IN THE MATTER OF

PATENT APPLICATION

C E R T I F I C A T E

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[Title of the Invention] LIQUID CRYSTAL DISPLAY DEVICE

[Claims]

[Claim 1] A liquid crystal display device, comprising:

a liquid crystal cell comprising a pair of substrates having electrodes and a liquid crystal layer interposed between the pair of substrates;

first and second polarizers arranged on either side of the liquid crystal cell; and

a first retardation plate arranged between the liquid crystal cell and the first polarizer, and a second retardation plate arranged between the liquid crystal cell and the second polarizer;

wherein:

each of the first and second retardation plates has an optical axis in a plane parallel to surfaces of the substrates and provides a retardation of substantially $\lambda/4$, the optical axis of the first retardation plate being perpendicular to the optical axis of the second retardation plate;

polarizing axes of the first and second polarizers are arranged at an angle of 45° with respect to the optical axes of the first and second retardation plates; and

the liquid crystal cell is arranged such that a state of alignment of liquid crystal molecules changes, accompanied by a change in a polar angle and/or a change in an azimuth angle,

upon application of voltage.

[Claim 2] A liquid crystal display device, comprising:

a liquid crystal cell comprising a pair of substrates having electrodes and a liquid crystal layer interposed between the pair of substrates;

first and second polarizers arranged on either side of the liquid crystal cell;

a first retardation plate arranged between the liquid crystal cell and the first polarizer; and

a second retardation plate arranged between the liquid crystal cell and the second polarizer;

wherein:

each of the first and second retardation plates has an optical axis in a plane parallel to surfaces of the substrates and provides a retardation of substantially $\lambda/4$, the optical axis of the first retardation plate being perpendicular to the optical axis of the second retardation plate;

polarizing axes of the first and second polarizers are arranged at an angle of 45° with respect to the optical axes of the first and second retardation plates; and

an azimuth angle distribution exists in a state of alignment of liquid crystal molecules when the liquid crystal molecules are aligned horizontally or obliquely with respect to the surfaces of the substrates.

[Claim 3] A liquid crystal display device according to

claim 1 or 2, wherein at least a portion of the liquid crystal molecules are aligned in an azimuth angle except for 45° from the polarizing axes of the polarizers.

[Claim 4] A liquid crystal display device according to claim 1 or 2, wherein liquid crystal of the liquid crystal cell is of a vertical alignment type, the liquid crystal cell includes a structure or a slit arranged on or in the electrode of at least one of the substrates, and a state of alignment of the liquid crystal molecules located on one side of the structure or the slit is different from a state of alignment of liquid crystal molecules located on the other side of the structure or the slit.

[Claim 5] A liquid crystal display device according to claim 4, wherein the liquid crystal molecules located on the structure or slit are aligned, accompanied by a change in the azimuth angle, upon application of voltage.

[Claim 6] A liquid crystal display device, comprising:

a liquid crystal cell comprising a pair of substrates having electrodes and a liquid crystal layer interposed between the pair of substrates;

first and second polarizers arranged on either side of the liquid crystal cell; and

a first retardation plate arranged between the liquid crystal cell and the first polarizer, and a second retardation plate arranged between the liquid crystal cell and the second

polarizer;

wherein:

each of the first and second retardation plates has an optical axis in a plane parallel to surfaces of the substrates and provides a retardation of substantially $\lambda/4$, the optical axis of the first retardation plate being perpendicular to the optical axis of the second retardation plate;

polarizing axes of the first and second polarizers are arranged at an angle of 45° with respect to the optical axes of the first and second retardation plates;

liquid crystal of the liquid crystal cell is of a vertical alignment type, the liquid crystal cell includes a structure or a slit arranged on or in the electrode of at least one of the substrates, and a state of alignment of liquid crystal molecules located on one side of the structure or the slit is different from a state of alignment of liquid crystal molecules located on the other side of the structure or the slit; and

at least one of the pair of substrates has a electrically conductive linear structure.

[Claim 7] A liquid crystal display device, comprising:

a liquid crystal cell comprising a pair of substrates having electrodes and a liquid crystal layer interposed between the pair of substrates;

first and second polarizers arranged on either side of

the liquid crystal cell; and

a first retardation plate arranged between the liquid crystal cell and the first polarizer, and a second retardation plate arranged between the liquid crystal cell and the second polarizer;

wherein:

each of the first and second retardation plates has an optical axis in a plane parallel to surfaces of the substrates and provides a retardation of substantially $\lambda/4$, the optical axis of the first retardation plate being perpendicular to the optical axis of the second retardation plate;

polarizing axes of the first and second polarizers are arranged at an angle of 45° with respect to the optical axes of the first and second retardation plates;

liquid crystal of the liquid crystal cell is of a vertical alignment type, the liquid crystal cell includes a structure or a slit arranged on or in the electrode of at least one of the substrates, and a state of alignment of liquid crystal molecules located on one side of the structure or the slit is different from a state of alignment of liquid crystal molecules located on the other side of the structure or the slit; and

a retardation in the plane of the retardation plate is not less than 120 nm and not more than 160 nm.

[Claim 8] A liquid crystal display device according to

claim 7, wherein an angle between an absorbing axis of the polarizers and an aligning direction or an inclining direction of the liquid crystal molecules is not less than 5°, and a contrast characteristic is symmetrical with respect to the horizontal direction.

[Claim 9] A liquid crystal display device according to claim 7, wherein at least one optical layer having a negative retardation is arranged between the retardation plate and the liquid crystal cell or between the retardation plate and the polarizer.

[Claim 10] A liquid crystal display device, comprising:

a liquid crystal cell comprising a pair of substrates having electrodes and a liquid crystal layer interposed between the pair of substrates; and

a film causing light to scatter in a specific direction;

wherein liquid crystal of the liquid crystal cell is of a vertical alignment type, and the liquid crystal cell includes a structure or a slit arranged on or in the electrode of at least one of the substrates, and a state of alignment of liquid crystal molecules located on one side of the structure or the slit is different from a state of alignment of liquid crystal molecules located on the other side of the structure or the slit.

[Claim 11] A liquid crystal display device according to claim 10, further comprising a uniaxial stretched film, a

biaxial stretched film and a film having a negative retardation in order to improve a viewing angle characteristic of the liquid crystal display device.

[Claim 12] A liquid crystal display device, comprising:

a liquid crystal cell comprising a pair of substrates having electrodes and a liquid crystal layer interposed between the pair of substrates;

first and second polarizers arranged on either side of the liquid crystal cell; and

a first retardation plate arranged between the liquid crystal cell and the first polarizer, and a second retardation plate arranged between the liquid crystal cell and the second polarizer;

wherein:

each of the first and second retardation plates has an optical axis in a plane parallel to surfaces of the substrates and provides a retardation of substantially $\lambda/4$, the optical axis of the first retardation plate being perpendicular to the optical axis of the second retardation plate;

polarizing axes of the first and second polarizers are arranged at an angle of 45° with respect to the optical axes of the first and second retardation plates; and

the liquid crystal layer of the liquid crystal cell contains liquid crystal and a resin coexisting with the liquid crystal.

[Claim 13] A liquid crystal display device, comprising:

a liquid crystal cell comprising a pair of substrates having electrodes and a liquid crystal layer interposed between the pair of substrates;

first and second polarizers arranged on either side of the liquid crystal cell; and

a first retardation plate arranged between the liquid crystal cell and the first polarizer, and a second retardation plate arranged between the liquid crystal cell and the second polarizer;

wherein:

each of the first and second retardation plates has an optical axis in a plane parallel to surfaces of the substrates and provides a retardation of substantially $\lambda/4$, the optical axis of the first retardation plate being perpendicular to the optical axis of the second retardation plate;

polarizing axes of the first and second polarizers are arranged at an angle of 45° with respect to the optical axes of the first and second retardation plates; and

liquid crystal of the liquid crystal cell is of a vertical alignment type, a polymer network is formed in the liquid crystal layer of the liquid crystal cell, and a pretilt of liquid crystal molecules and an inclination direction of the liquid crystal molecules upon application of voltage are regulated by the polymer network.

[Detailed Description of the Invention]

[0001]

[Field of the Invention]

The present invention relates to a liquid crystal display device having an improved viewing angle characteristic.

[0002]

[Prior Art]

Regarding a liquid crystal display device, it is known that the contrast of the display in the case where the image area is viewed in an oblique direction is different from the contrast of the display in the case where the image area is viewed from the front (the viewing angle characteristic). Therefore, there is a demand for a liquid crystal display device having an improved viewing angle characteristic.

Japanese Unexamined Patent Publications No. 1-270024 and No. 2000-29010 disclose a liquid crystal display device including a vertical alignment type liquid crystal cell, first and second polarizers arranged on either side of the liquid crystal cell, a first $\lambda/4$ plate arranged between the liquid crystal cell and the first polarizer, and a second $\lambda/4$ plate arranged between the liquid crystal cell and the second polarizer. By providing the polarizers and the $\lambda/4$ plates, it is possible to improve the viewing angle characteristic in the case where the image area is viewed in an oblique direction.

[0003]

However, in the liquid crystal display device having the polarizers and the $\lambda/4$ plates, although the viewing angle characteristic can be improved, the range of the viewing angle, in which the display can be viewed with high contrast, is relatively small.

As a technique for improving the viewing angle characteristic of the liquid crystal display device, there is provided a technique of alignment division. By the technique of alignment division, one pixel is divided into a plurality of regions having different states of alignment of liquid crystal molecules, so that the display can be viewed with high contrast even when the image area is viewed in an oblique direction, like when the image area is viewed from the front. Especially, the applicant of the present application has proposed a vertical alignment type liquid crystal display device having structures or slits which linearly extend on or in electrodes on the substrates between which the liquid crystal layer is interposed.

[0004]

In this liquid crystal display device, most liquid crystal molecules are aligned substantially perpendicularly to the substrate surfaces when voltage is not applied. However, liquid crystal molecules located close to a structure or slit tend to be aligned perpendicular to a wall surface of the structure or slit and are pretilted with respect to the

substrate surfaces. When voltage is applied, the liquid crystal molecules located close to the structure or slit are inclined in a predetermined direction according to the pretilt, and most liquid crystal molecules are inclined according to the liquid crystal molecules located close to the structure or slit.

[0005]

The direction of alignment of liquid crystal molecules located on one side of the structure or slit is opposite to the direction of alignment of liquid crystal molecules located on the other side of the structure or slit. Therefore, two regions in which the states of alignment are different from each other are formed on both sides of the structure or slit, respectively. Therefore, in this liquid crystal display device, even if rubbing is not conducted, it is possible to realize alignment division like in the case where pretilt is provided by rubbing. By the alignment division, it is possible to obtain an excellent viewing angle characteristic with high contrast in a wide viewing angle range. The liquid crystal display device having alignment division is disclosed, for example, in Japanese Unexamined Patent Publication No. 11-352489.

[0006]

Japanese Patent No. 2945143 discloses a liquid crystal display device in which a polymer dispersed liquid crystal

panel is interposed between polarizers located in a crossed Nicols arrangement. Japanese Unexamined Patent Publication No. 2000-347174 discloses a network-like polymer dispersed liquid crystal display device.

[0007]

[Problems to be Solved by the Invention]

In a liquid crystal display device having such alignment division, the state of alignment of most liquid crystal molecules in one pixel is substantially controlled according to predetermined structures or slits when voltage is applied. However, there are cases where the state of alignment of a portion of the liquid crystal molecules in one pixel cannot be controlled according to the predetermined structures or slits. For example, liquid crystal molecules located close to the bus lines located in a periphery of the pixel tend to be aligned perpendicularly to the wall surface of the bus lines. Therefore, the state of alignment of these liquid crystal molecules is different from the state of alignment of the liquid crystal molecules controlled according to the predetermined structures or slits, which could be a cause of deterioration of brightness. Liquid crystal molecules on the predetermined structures or slits are aligned in parallel to the predetermined structures or slits. The polarizers are arranged so that the polarizing axes thereof can form an angle of 45° with respect to the director of the liquid crystal

molecules when voltage is applied. However, a portion of the liquid crystal molecules become parallel to the polarizing axes, which could be a cause of deterioration of brightness.

[0008]

An object of the present invention is to provide a liquid crystal display device by which an excellent image area can be viewed over a wide viewing angle and which provides high brightness.

[0009]

[Means for Solving the Problems]

According to a first aspect of the present invention, there is provided a liquid crystal display device comprising a liquid crystal cell comprising a pair of substrates having electrodes and a liquid crystal layer interposed between the pair of substrates; first and second polarizers arranged on either side of the liquid crystal cell; and a first retardation plate arranged between the liquid crystal cell and the first polarizer, and a second retardation plate arranged between the liquid crystal cell and the second polarizer. Each of the first and second retardation plates has an optical axis in a plane parallel to surfaces of the substrates and provides a retardation of substantially $\lambda/4$, the optical axis of the first retardation plate being perpendicular to the optical axis of the second retardation plate. Polarizing axes of the first and second polarizers are arranged at an angle of

45° with respect to the optical axes of the first and second retardation plates. The liquid crystal cell is arranged such that a state of alignment of liquid crystal molecules changes, accompanied by a change in a polar angle and a change in an azimuth angle, upon application of voltage.

[0010]

According to the above structure, it is possible to obtain a liquid crystal display device by which an excellent image area can be viewed over a wide viewing angle and which provides high brightness.

With a structure by which an azimuth angle distribution is provided in the state of alignment of the liquid crystal molecules when the liquid crystal molecules are arranged horizontally or obliquely with respect to the substrate surfaces, the transmittance can be improved.

According to a second aspect of the present invention, there is provided a liquid crystal display device, comprising a liquid crystal cell comprising a pair of substrates having electrodes and a liquid crystal layer interposed between the pair of substrates; first and second polarizers arranged on either side of the liquid crystal cell; and a first retardation plate arranged between the liquid crystal cell and the first polarizer, and a second retardation plate arranged between the liquid crystal cell and the second polarizer. Each of the first and second retardation plates has an optical

axis in a plane parallel to surfaces of the substrates and provides a retardation of substantially λ/4, the optical axis of the first retardation plate being perpendicular to the optical axis of the second retardation plate. Polarizing axes of the first and second polarizers are arranged at an angle of 45° with respect to the optical axes of the first and second retardation plates. Liquid crystal of the liquid crystal cell is of a vertical alignment type, the liquid crystal cell includes a structure or a slit arranged on or in the electrode of at least one of the substrates, and a state of alignment of liquid crystal molecules located on one side of the structure or the slit is different from a state of alignment of liquid crystal molecules located on the other side of the structure or the slit. At least one of the pair of substrates has a electrically conductive linear structure.

[0011]

According to the above structure, it is possible to obtain a liquid crystal display device by which an excellent image area can be viewed over a wide viewing angle and which provides high brightness.

According to a third aspect of the present invention, there is provided a liquid crystal display device, comprising a liquid crystal cell comprising a pair of substrates having electrodes and a liquid crystal layer interposed between the pair of substrates; first and second polarizers arranged on

either side of the liquid crystal cell; and a first retardation plate arranged between the liquid crystal cell and the first polarizer, and a second retardation plate arranged between the liquid crystal cell and the second polarizer. Each of the first and second retardation plates has an optical axis in a plane parallel to surfaces of the substrates and provides a retardation of substantially $\lambda/4$, the optical axis of the first retardation plate being perpendicular to the optical axis of the second retardation plate. Polarizing axes of the first and second polarizers are arranged at an angle of 45° with respect to the optical axes of the first and second retardation plates. Liquid crystal of the liquid crystal cell is of a vertical alignment type, the liquid crystal cell includes a structure or a slit arranged on or in the electrode of at least one of the substrates, and a state of alignment of liquid crystal molecules located on one side of the structure or the slit is different from a state of alignment of liquid crystal molecules located on the other side of the structure or the slit. A retardation in the plane of the retardation plate is not less than 120 nm and not more than 160 nm.

[0012]

According to the above structure, it is possible to obtain a liquid crystal display device by which an excellent image area can be viewed over a wide viewing angle and which provides high brightness.

According to a fourth aspect of the present invention, there is provided a liquid crystal display device, comprising a liquid crystal cell comprising a pair of substrates having electrodes and a liquid crystal layer interposed between the pair of substrates; and a film causing light to scatter in a specific direction. Liquid crystal of the liquid crystal cell is of a vertical alignment type, and the liquid crystal cell includes a structure or a slit arranged on or in the electrode of at least one of the substrates, and a state of alignment of liquid crystal molecules located on one side of the structure or the slit is different from a state of alignment of liquid crystal molecules located on the other side of the structure or the slit.

[0013]

According to the above structure, it is possible to obtain a liquid crystal display device by which an excellent image area can be viewed over a wide viewing angle and which provides high brightness.

According to a fifth aspect of the present invention, there is provided a liquid crystal display device, comprising a liquid crystal cell comprising a pair of substrates having electrodes and a liquid crystal layer interposed between the pair of substrates; first and second polarizers arranged on either side of the liquid crystal cell; and a first retardation plate arranged between the liquid crystal cell and

the first polarizer, and a second retardation plate arranged between the liquid crystal cell and the second polarizer. Each of the first and second retardation plates has an optical axis in a plane parallel to surfaces of the substrates and provides a retardation of substantially $\lambda/4$, the optical axis of the first retardation plate being perpendicular to the optical axis of the second retardation plate. Polarizing axes of the first and second polarizers are arranged at an angle of 45° with respect to the optical axes of the first and second retardation plates. The liquid crystal layer of the liquid crystal cell contains liquid crystal and a resin coexisting with the liquid crystal.

[0014]

According to the above structure, it is possible to obtain a liquid crystal display device by which an excellent image area can be viewed over a wide viewing angle and which provides high brightness.

According to a sixth aspect of the present invention, there is provided a liquid crystal display device, comprising a liquid crystal cell comprising a pair of substrates having electrodes and a liquid crystal layer interposed between the pair of substrates; first and second polarizers arranged on either side of the liquid crystal cell; and a first retardation plate arranged between the liquid crystal cell and the first polarizer, and a second retardation plate arranged

between the liquid crystal cell and the second polarizer. Each of the first and second retardation plates has an optical axis in a plane parallel to surfaces of the substrates and provides a retardation of substantially $\lambda/4$, the optical axis of the first retardation plate being perpendicular to the optical axis of the second retardation plate. Polarizing axes of the first and second polarizers are arranged at an angle of 45° with respect to the optical axes of the first and second retardation plates. Liquid crystal of the liquid crystal cell is of a vertical alignment type, a polymer network is formed in the liquid crystal layer of the liquid crystal cell, and a pretilt of liquid crystal molecules and an inclination direction of the liquid crystal molecules upon application of voltage are regulated by the polymer network.

[0015]

According to the above structure, it is possible to obtain a liquid crystal display device by which an excellent image area can be viewed over a wide viewing angle and which provides high brightness.

[0016]

[Embodiments of the Invention]

Hereinafter, embodiments of the present invention will be described with reference to the drawings.

Fig. 1 is a view showing a liquid crystal display device of a first embodiment of the present invention. A liquid

crystal display device 10 includes a liquid crystal cell 12. The liquid crystal cell 12 includes a pair of substrates 14 and 16 having electrodes, and a liquid crystal layer 18 interposed between the pair of substrates. Further, the liquid crystal display device 10 includes first and second polarizers 20 and 22 arranged on either side of the liquid crystal cell 12, a first retardation plate 24 arranged between the liquid crystal cell 12 and the first polarizer 20, and a second retardation plate 26 arranged between the liquid crystal cell 12 and the second polarizer 22.

[0017]

Each of the first and second retardation plates 24 and 26 has an optical axis 24A or 26A in a plane parallel to surfaces of the substrates and provides a retardation of substantially $\lambda/4$. The optical axis 24A of the first retardation plate 24 is perpendicular to the optical axis 26A of the second retardation plate 26. Polarizing axes 20A and 22A of the first and second polarizers 20 and 22 are arranged at an angle of 45° with respect to the optical axes 24A and 26A of the first and second retardation plates 24 and 26.

[0018]

Liquid crystal 18 of the liquid crystal cell 12 is of a vertical alignment type. The liquid crystal cell 12 is structured such that the state of alignment of liquid crystal molecules changes, accompanied by a change in the polar angle

and a change in the azimuth angle, upon application of voltage.

Fig. 2 is a schematic cross-sectional view showing the liquid crystal cell 12 of Fig. 1, and Fig. 3 is a schematic plan view showing linear structures and the liquid crystal molecules of the liquid crystal cell 12 of Fig. 2. The first substrate 14 has an electrode 28 and linear structures (ribs) 30 formed of a dielectric substance on the electrode 28. The second substrate 16 has an electrode 32 and linear structures (ribs) 34 formed of a dielectric substance on the electrode 32. Further, the first substrate 14 and the second substrate 16 have vertical alignment films (not shown), and the liquid crystal 18 has a negative dielectric constant anisotropy. One of the electrode 28 of the first substrate 14 and the electrode 34 of the second substrate 16 is a common electrode, and the other is a pixel electrode formed together with a TFT. Further, the substrate having the common electrode has a color filter.

[0019]

Only two electrodes 28 of the first substrate 14 are shown; however, it is possible to arrange a desired number of electrodes in parallel to each other. Only one electrode 34 of the second substrate 16 is shown; however, it is possible to arrange a desired number of electrodes in parallel to each other. As shown in Fig. 3, the electrodes 28 and 34 are

alternately arranged so that they can be parallel to each other when viewed on a plan view.

[0020]

Generally in a vertical alignment type liquid crystal display device, when voltage is not applied, liquid crystal molecules are aligned substantially perpendicularly to the substrate surfaces; and when voltage is applied, liquid crystal molecules are inclined with respect to the substrate surfaces. When the linear structures 30 and 34 are provided, most of the liquid crystal molecules are aligned substantially perpendicularly to the substrate surfaces when voltage is not applied, but the liquid crystal molecules 18X and 18Y located close to the linear structures 30 and 34 tend to align perpendicularly to the wall surfaces of the linear structures 30 and 34 and are pretilted with respect to the substrate surfaces. Therefore, when voltage is applied, the liquid crystal molecules 18X and 18Y located close to the linear structures 30 and 34 are inclined in a predetermined direction according to the pretilt, and most of the liquid crystal molecules are inclined according to these liquid crystal molecules 18X and 18Y.

[0021]

The direction of alignment of the liquid crystal molecules 18X located on one side of the linear structure 34 is opposite to the direction of alignment of the liquid

crystal molecules 18Y located on the other side of the linear structure 34, so two regions in which the states of alignment are different from each other are formed on both sides of the linear structures 34, respectively. This is also applied to the linear structures 30. Accordingly, in this liquid crystal display device 10, even if rubbing is not conducted, it is possible to realize alignment division like in the case where pretilt is provided by rubbing. By the alignment division, it is possible to obtain an excellent viewing angle characteristic with high contrast in a wide viewing angle range.

[0022]

That is, in a common liquid crystal display device, when an image area is viewed in the direction of the major axis of the inclined liquid crystal molecules, the image area looks whitish; and when the image area is viewed in an axial direction to the direction of the major axis of the inclined liquid crystal molecules, the image area looks blackish. With alignment division, there are the liquid crystal molecules 18X which are inclined onto one side, and the liquid crystal molecules 18Y which are inclined onto the other side, in one pixel. Therefore, a whitish image and a blackish image are averaged in the image area. Accordingly, in whichever oblique direction the image area may be viewed, the image area can be viewed with high contrast in the same manner as in the case

where the image area is viewed from the front. In this way, the vertical alignment type liquid crystal display device in which alignment division is conducted can realize an excellent viewing angle characteristic.

[0023]

Fig. 4 is a view showing portion A of Fig. 3 in detail. In such a liquid crystal display device with alignment division, the state of alignment of most liquid crystal molecules in one pixel is substantially controlled according to the predetermined structure 30 and 34 when voltage is applied. That is, when voltage is applied, the state of alignment of liquid crystal molecules changes from a state of alignment in which the liquid crystal molecules are substantially perpendicular to the substrate surfaces to a state of alignment in which the liquid crystal molecules are inclined with respect to the substrate surfaces, accompanied by a change in the polar angle.

[0024]

However, in some cases, the state of alignment of a portion of the liquid crystal molecules upon application of voltage cannot be controlled only by the predetermined structure 30 or 34. For example, as described above, the liquid crystal molecules 18X which are inclined onto one side with respect to the structure 30 or 34, and the liquid crystal molecules 18Y which are inclined onto the other side with

respect to the structure 30 or 34, must be continuously aligned to each other. Therefore, liquid crystal molecules 18P and 18Q, which are located intermediately between the liquid crystal molecules 18X and 18Y and on the structure 30 or 34, are aligned in parallel with the structure 30 or 34. Liquid crystal molecules 18R and 18S adjacent to the liquid crystal molecules 18P and 18Q are aligned at an angle of, for example, 45° with respect to the structure 30 or 34.

[0025]

The polarizers 20 and 22 are arranged in such a manner that the polarizing axes 20A and 22A form an angle of 45° with respect to the director of the liquid crystal molecules upon application of voltage. The director of the liquid crystal molecules 18X, 18Y, 18P and 18Q shown in Fig. 4 forms an angle of 45° with respect to the polarizing axes 20A and 22A. However, the director of the liquid crystal molecules 18R and 18S becomes parallel to the polarizing axes 20A and 22A. Therefore, black is displayed when white should be displayed, and black lines represented by reference numeral 36 appear. That is, there is a problem that brightness is deteriorated.

[0026]

Further, since the inclining direction of the liquid crystal molecules 18R and 18S on the structure 30 or 34 cannot be controlled, a portion of the liquid crystal molecules 18R on the structure 30 or 34 and another portion of the liquid

crystal molecules 18S on the structure 30 or 34 are aligned opposite to each other, immediately after voltage is applied. When a certain time passes after the application of voltage, the liquid crystal molecules 18R and 18S, which are aligned opposite to each other, are rotated in, for example, a plane of the sheet of Fig. 4 (the state of alignment changes, accompanied by a change in the azimuth angle) and therefore, most of the liquid crystal molecules 18R and 18S on the structure 30 or 34 are directed in the same direction and stabilized. Responsiveness is determined at the point of time when the state of alignment of the liquid crystal molecules 18R and 18S is stabilized. Accordingly, the change in the state of alignment of the liquid crystal molecules 18R and 18S accompanied by the change in the azimuth angle causes a abnormality in the response state of the liquid crystal display device.

[0027]

An explanation has been given above of the liquid crystal display device having the structures 30 and 34. The same is applicable to a liquid crystal display device having slits instead of the structures 30 and 34, which will be explained later. Not only the state of alignment of the liquid crystal molecules 18R and 18S on the structures 30 or 34, but also the state of alignment of the liquid crystal molecules located close to the pixel edge, is different from the state of

alignment of the liquid crystal molecules 18X and 18Y on either side of the structures 30 or 34. This could be a cause of deterioration of brightness.

[0028]

The present inventors have found that the deterioration of brightness and the deterioration of the responsiveness of the liquid crystal display device with alignment division as described above can be solved by providing the first retardation plate (λ/4) 24 and the second retardation plate (λ/4) 26, as shown in Fig. 1.

Fig. 15 explains an action of the retardation plate (λ/4) 24. In Fig. 15(A), the polarizing axes 20A and 22A of the first and second polarizers 20 and 22 are perpendicular to each other, and the optical axes (slow axes) 24A and 26A of the first and second retardation plates 24 and 26 are perpendicular to each other. The polarizing axes 20A and 22A of the first and second polarizers 20 and 22 and the optical axes (slow axes) 24A and 26A of the first and second retardation plates 24 and 26 are arranged at an angle of 45° with each other. In Fig. 15(A), it is assumed that the optical axis 24A, 26A of the first retardation plate 24 extends along the y-axis, and the optical axis 26A of the second retardation plate 26 extends along the x-axis. The liquid crystal layer 18 is assumed to entirely have a director 18D. The polarizing axes 20A and 22A of the first and second

polarizers 20 and 22 are arranged at an angle of 45° with respect to the director 18D of the liquid crystal layer 18.

[0029]

Fig. 15(B) shows the state of light passing through the first polarizer 20, the first retardation plate 24, the liquid crystal layer 18, the second retardation plate 26 and the second polarizer 22. Illumination light incident on the first polarizer 20 becomes linearly polarized light; the linearly polarized light incident on the first retardation plate 24 becomes counterclockwise circularly polarized light; the circularly polarized light incident on the liquid crystal layer 18 becomes clockwise circularly polarized light; the circularly polarized light incident on the second retardation plate 26 becomes linearly polarized light; and the linearly polarized light incident on the second polarizer 22 is transmitted through the second polarizer 22. In this case, the retardation of the liquid crystal layer 18 was $\lambda/2$.

[0030]

Fig. 16 shows the cases in which the retardation of the liquid crystal layer 18 is $\lambda/2$. (A) shows a case in which a director 18D1 of the liquid crystal layer 18 is parallel to the y-axis, (B) shows a case in which a director 18D2 of the liquid crystal layer 18 is parallel to the x-axis, and (C) shows a case in which a director 18D3 of the liquid crystal layer 18 is arranged at an angle of 45° with respect to the x-

axis. As can be seen in Fig. 16, all the light transmitted through the liquid crystal layer 18 becomes the same circularly polarized light, irrespective of the direction of the director 18 of the liquid crystal layer 18. Accordingly, the transmittance of the light finally transmitted through the second polarizer 22 does not depend upon the direction of the director 18D of the liquid crystal layer 18.

[0031]

Fig. 17 shows the cases in which the retardation of the liquid crystal layer 18 is $\lambda/4$. (A) shows a case in which the director 18D1 of the liquid crystal layer 18 is parallel to the y-axis, (B) shows a case in which the director 18D2 of the liquid crystal layer 18 is parallel to the x-axis, and (C) shows a case in which the director 18D3 of the liquid crystal layer 18 is arranged at an angle of 45° with respect to the x-axis. In (A) where the retardation of the liquid crystal layer 18 is $\lambda/4$ and the director 18D1 of the liquid crystal layer 18 is parallel to the y-axis, circularly polarized light transmitted through the first retardation plate 24 is transmitted through the liquid crystal layer 18 and becomes linearly polarized light. This linearly polarized light, when transmitting through the second retardation plate 26, becomes circularly polarized light, and a component of the circularly polarized light in the direction of y-axis (L22) is transmitted through the second polarizer 22.

[0032]

In (B) where the retardation of the liquid crystal layer 18 is λ/4 and the director 18D2 of the liquid crystal layer 18 is parallel to the x-axis, circularly polarized light transmitted through the first retardation plate 24 is transmitted through the liquid crystal layer 18 and becomes linearly polarized light. This linearly polarized light, when transmitting through the second retardation plate 26, becomes circularly polarized light, and a component of the circularly polarized light in the direction of y-axis (L22) is transmitted through the second polarizer 22.

[0033]

In (C) where the retardation of the liquid crystal layer 18 is λ/4 and the director 18D3 of the liquid crystal layer 18 is arranged at an angle of 45° with respect to the x-axis, circularly polarized light transmitted through the first retardation plate 24 is transmitted through the liquid crystal layer 18 and becomes linearly polarized light. This linearly polarized light, when transmitting through the second retardation plate 26, becomes linearly polarized light, and a component of the linearly polarized light in the direction of y-axis (L22) is transmitted through the second polarizer 22.

[0034]

In this way, the directions of polarization of the polarized light transmitted through the second retardation

plate 26 are different from each other, but the transmittance of the light finally transmitted through the second polarizer 22 does not depend upon the direction of the director 18D of the liquid crystal layer 18.

In the case where the retardation of the liquid crystal layer 18 is different from $\lambda/2$ or $\lambda/4$, circularly polarized light incident on the liquid crystal layer 18 is transmitted through the liquid crystal layer 18 and becomes elliptically polarized light. In this case also, the transmittance of the light transmitted through the second retardation plate 26 and the second polarizer 22 does not depend upon the direction of the director 18D of the liquid crystal layer 18.

[0035]

Accordingly, as explained referring to Fig. 4, even when the liquid crystal cell 12 has minute portions containing the liquid crystal molecules 18X, 18Y, 18P, 18Q, 18R and 18S with different directors, circularly polarized light is transmitted through the liquid crystal layer 18 and the second polarizer 22 in substantially the same manner, without being affected by the difference in the directors. Therefore, the deterioration of brightness can be prevented.

[0036]

The fact that transmittance does not depend upon the director of the liquid crystal molecules is advantageous in the aspect of the responsiveness. That is, when a certain

time passes after the application of voltage, the liquid crystal molecules 18R and 18S, the directions of which are opposite to each other, are rotated in, for example, a plane of the sheet of Fig. 4 (the state of alignment changes accompanied by a change in the azimuth angle), and the most of the liquid crystal molecules 18R and 18S on the structure 30 or 34 are directed in the same direction and stabilized. Conventionally, the responsiveness is determined at a point of time when the state of alignment of the liquid crystal molecules 18R and 18S is stabilized. However, according to the present invention, the intensity of the polarized light transmitted through the second polarizer 22 has already become constant at a point of time when the liquid crystal molecules 18R and 18S on the structure 30 or 34 are inclined in opposite directions from each other. Therefore, it is not necessary to wait for a change in the state of alignment of the liquid crystal molecules 18R and 18S accompanied by a change in the azimuth angle. Accordingly, the response time of the liquid crystal display device can be reduced.

[0037]

Fig. 18 is a view showing an example of an image area of a conventional liquid crystal display device with alignment division. In Fig. 18, the black lines 36 appear, which have been explained referring to Fig. 4. The black lines 36 can be a cause of the deterioration of brightness.

Fig. 19 is a view showing an example of the image area of the liquid crystal display with alignment division and the first and second retardation plates 24 and 26. In Fig. 18, the black lines 36 appear which have been explained referring to Fig. 4. The black lines 36 of Fig. 18 have disappeared.

[0038]

Fig. 20(A) is a view showing the relation between the applied voltage and the transmittance of the liquid crystal display devices, with alignment division, of the prior art and the present invention. A curve plotted by black points is regarding the conventional liquid crystal display device, and a curve plotted by white points is regarding the liquid crystal display device of the present invention. In both cases, the alignment division was realized by a combination of the linear structures 30 and the slits 38 (shown in Figs. 5 and 6). The transmittance was increased by 1.19 times at a voltage of 5.4 V. Fig. 20(B) shows that the responsiveness is improved.

[0039]

Figs. 5 to 14 are views showing variations of the liquid crystal cell with the alignment division shown in Figs. 2 to 4. The liquid crystal cells shown in Figs. 5 to 14 can be adopted as the liquid crystal cell 12 shown in Fig. 1, and provide the action which is explained referring to Figs. 15 to 20.

In Figs. 5 and 6, the first substrate 14 has the electrode 28 and the linear structures (ribs) 30 formed of a dielectric substance on the electrode 28. The second substrate 16 has the electrode 32 and slits 38 formed in the electrode 32. The slit 38 includes a slit base section 38a extending in the same manner as that of the linear structure 34 shown in Figs. 2 and 3, and minute slit sections 38b extending in a direction perpendicular to the extending direction of the slit base section 38a. The slit base sections 38a have the same action as that of the linear structure 34 shown in Fig. 3. Since the minute slit sections 38b are located in a portion forming a display domain, the influence of the electric field strain is transmitted especially to the liquid crystal molecules constituting the display domain at high speed, it is possible to improve the performance of response of middle tones. Especially, when the minute slit sections 38b are shaped so as to extend in parallel to the substrate surface like a group of triangles shown in Fig. 6, the speed of response can be highly improved.

[0040]

In Figs. 7 to 9, the first substrate 14 includes the electrode 28 and the linear structures (ribs) 30 formed of a dielectric substance on the electrode 28, and the second substrate 16 includes the electrode 32 and the linear structures (ribs) 34 formed on the electrode 32. In this

example, the linear structures 30 on the first substrate 14 are arranged in a grating pattern, and the linear structures 34 on the second substrate 16 are arranged in a grating pattern but shifted from the linear structures 30 on the first substrate 14. In this way, four liquid crystal alignment regions including liquid crystal molecules 18A, 18B, 18C, 18D are formed by the linear structures 30 and 34 crossing each other. In this case, since the directions of alignment of the liquid crystal molecules 18A, 18B, 18C and 18D are different in the four liquid crystal alignment regions, the effect obtained by the alignment division can be further enhanced. It should be noted that polarizing axes 20A and 22A of the first and second polarizers 20 and 22 are arranged in parallel to the linear structures 30 and 34, but on the linear structures 30 and 34, the liquid crystal molecules 18P and 18Q exist, which extend in parallel to the linear structures 30 and 34 and are arranged in opposite directions to each other. The liquid crystal molecules 18P and 18Q could cause the black lines 36 and deteriorate the responsiveness. By providing the first and second retardation plates 24 and 26, it is possible to improve the brightness and the response time in the same manner as described above.

[0041]

In Figs. 10 and 11, the first substrate 14 has the electrode 28 but no linear structures or no slits. The second

substrate 16 has the electrode 32 and slits 38 which are formed in a fishbone pattern in the electrode 32. The slit 38 includes a slit base section 38a and minute slit sections 38b. The liquid crystal molecules 18A and 18B are aligned in the directions different from each other. The liquid crystal molecules 18R are located on the slit base section 38a.

[0042]

In Figs. 12 to 14, the first substrate 14 has the electrode 28 but no linear structure or slit. The second substrate 16 has the electrode 32 and slits 38 which are formed in a fishbone pattern in the electrode 32. The slit 38 includes a slit base section 38a and minute slit sections 38b. The minute slit sections 38b become narrower toward the tip thereof. The liquid crystal molecules 18A and 18B are aligned in directions different from each other. The liquid crystal molecules 18R are located on the slit base section 38a.

[0043]

Fig. 21 is a view showing another example of the liquid crystal cell with alignment division. The liquid crystal cell 12 is structured such that the liquid crystal layer 18 is interposed between the first substrate 14 and the second substrate 16. The first and second retardation plates 24 and 26 and the first and second polarizers 20 and 22 are arranged on either side of the liquid crystal cell 12 (see Fig. 1). The first substrate 14 is a color filter substrate, and the

second substrate 16 is a TFT substrate. The liquid crystal cell 12 forms a liquid crystal panel of 15 inch XGA, and the pixel pitch is 297 μm.

[0044]

Regarding one pixel electrode 19 (electrode 32), the linear structures 30 of the first substrate 14 are formed in a bent shape, and the slits 38 of the second substrate 16 are also formed in a bent shape. In this case, alignment division with four divided regions can be realized. The linear structures 30 are made of an acrylic photosensitive material (for example, PC-335 manufactured by JSR), and the width of the linear structure 30 is 10 μm and the height thereof is 1.2 μm. The width of the slit 38 is 10 μm. The slits 38 are formed in the pixel electrode 19, and discontinuously so that an electric current can flow through the pixel electrode 19.

[0045]

The distance between the linear structure 30 and the slit 38 is 25 μm. The thickness of the liquid crystal cell 12 is 4.64 μm. For the first and second retardation plates (λ/4 plate) 24 and 26, PC (polycarbonate; for example, NRF-RF01A manufactured by Nitto Denko Corporation) was used. The retardation is 140 nm. However, it is possible to use a retardation plate made of other materials (for example, arton film). For the first and second polarizers 20 and 22, G1220DU manufactured by Nitto Denko Corporation was used.

[0046]

In the case where the polarizers 20 and 22 were located in a cross arrangement (the polarizing axes 20A and 22A were arranged vertically and horizontally in the sheet of Fig. 21; in this example, the polarizing axes 20A and 22A form an angle of 45° with respect to the main liquid crystal director), the white transmittance was 6.43%. With the same structure, in the case where the polarizers 20 and 22 were located in a 45° arrangement (for example, the polarizing axes 20A and 22A were arranged at an angle of 45° with respect to the vertical and the horizontal directions in Fig. 21), the white transmittance was 6.58%. The arrangement of the polarizers 20 and 22 is not limited to the cross arrangement and the 45° arrangement, and can be arbitrarily arranged. On the other hand, with a conventional liquid crystal display device having no retardation plate 24 or 26, the white transmittance was 5.05% in the case of the cross arrangement.

[0047]

In the embodiment, the gap distance between the linear structure 30 and the slit 38 is 25 μm, but this distance can be changed. In the case of the conventional liquid crystal display with alignment division but without the first and second retardation plates (λ/4 plate) 24 and 26, the following problem occurred; the speed of response is increased but the transmittance is decreased when the gap distance is decreased;

and the transmittance is increased but the speed of response is decreased when the gap distance is increased. These problems are all caused by a change in the azimuth angle of alignment of the liquid crystal molecules or a decrease or a change in the transmittance due to the change in the azimuth angle of alignment. In the present invention, since the transmittance does not depend upon the azimuth angle of alignment of the liquid crystal molecules, the influence such as the decrease of the transmittance or the decrease of the speed of response caused by the change in the gap distance is smaller as compared with the conventional art. Therefore, it is made possible to use a liquid crystal panel with a smaller gap distance or a larger gap distance which cannot be conventionally used, in accordance with the applications such as liquid crystal display devices for moving pictures or liquid crystal display devices for high brightness.

[0048]

Fig. 22 is a view showing another example of the liquid crystal cell with alignment division. Regarding one pixel electrode 19, the linear structures 30 of the first substrate 14 are formed in a bent shape, and the slits 38 of the second substrate 16 are also formed in a bent shape. The slit 38 is the same as that shown in Fig. 6. In this case, alignment division with four divided regions is realized. The width of the linear structure 30 and the slit 38 is 10 μm. The pitch

of the minute slit section is 6 μm, and the length thereof is 15 μm.

[0049]

The liquid crystal cell 12 is manufactured under substantially the same conditions as those of Fig. 21 except that the thickness thereof is 4.26 μm. In the case where the polarizers 20 and 22 were located in a cross arrangement, the white transmittance was 5.74%. With the same structure, in the case where the polarizers 20 and 22 were located in a 45° arrangement, the white transmittance was 5.88%. On the other hand, with a conventional liquid crystal display device having no retardation plate 24 or 26, in the case where the polarizers 20 and 22 were located in a cross arrangement, the white transmittance was 4.47%. In this example, since the cell thickness is smaller than that of the example shown in Fig. 21, the retardation of the liquid crystal layer 18 is decreased and, although the absolute value of the transmittance is slightly lower, the effect of improvement by providing the retardation plates is high like in the example shown in Fig. 21.

[0050]

Fig. 23 is a view showing still another example of the liquid crystal cell with alignment division. The first substrate 14 has the linear structures 30, and the second substrate 16 has the slits 38. The linear structures 30 and

the slits 38 are arranged in a grating pattern like the linear structures 30 and 34 of the liquid crystal cell 12 shown in Figs. 7 to 9. The width of the linear structure 30 is 8 μm, and the height thereof is 0.75 μm. The width of the slit 38 is 8 μm. The cell thickness is 4.02 μm. In the case where the polarizers 20 and 22 were located in a cross arrangement, the white transmittance was 5.86%. In the case where the polarizers 20 and 22 were located in a 45° arrangement, the white transmittance was 5.78%. On the other hand, with a conventional liquid crystal display device having no retardation plate 24 or 26, the white transmittance was 4.48% in the case of a cross arrangement.

[0051]

Fig. 24 is a view showing still another example of the liquid crystal cell with alignment division. This example includes two slits 38A and 38B of a fishbone pattern similar to the slit 38 of the fishbone pattern shown in Fig. 11. The cell thickness is 3.86 μm. The other conditions are the same as those of the example shown in Fig. 21. In the case where the polarizers 20 and 22 were located in a cross arrangement, the white transmittance was 6.26%. With the same structure, in the case where the polarizers 20 and 22 were located in a 45° arrangement, the white transmittance was 6.06%. On the other hand, with a conventional liquid crystal display device having no retardation plate 24 or 26, the white transmittance

was 5.12% in the case of a cross arrangement.

[0052]

Fig. 25 is a view showing the relation between the attained transmittance and the rise time with the alignment division shown in Fig. 24. The curve plotted by black triangles represents the alignment division of the structure shown in Fig. 24 with no retardation plates, and the curve plotted by white triangles represents the alignment division of the structure shown in Fig. 24 with the retardation plates. Conventionally, in this system, the response time in all the gradation levels including the middle tones is several hundred ms. Therefore, this system was not suitable for a device using liquid crystal, such as a liquid crystal monitor. By applying the present invention, a speed of response of 20 ms from black to white, and a speed of response of 90 ms even from black to a middle tone (25%), are realized. Therefore, this system can now be applied to a device using liquid crystal, such as a liquid crystal monitor.

[0053]

Figs. 26 to 28 are views showing the relation between the cell thickness and the transmittance. Fig. 26 shows the relation between the cell thickness and the transmittance in the case of alignment division realized by parallel linear structures (for example, Fig. 21). Fig. 27 shows the relation between the cell thickness and the transmittance in the case

of alignment division in a grating pattern (for example, Fig. 23). Fig. 28 shows the relation between the cell thickness and the transmittance in the case of alignment division in a fishbone pattern shown (for example, Fig. 24).

[0054]

In these views, the curve plotted by squares represents a case in which no retardation plate (λ/4) is provided and the polarizers are located in a cross arrangement, the curve plotted by triangles represents a case in which retardation plates (λ/4) are provided and the polarizers are located in a cross arrangement, and the curve plotted by black circles represents a case in which retardation plates (λ/4) are provided and the polarizers are located in a 45° arrangement.

In Fig. 26, according to the curve plotted by the squares, when the cell thickness is 4.2 μm, the transmittance is 4.4%. This is equivalent to the liquid crystal display device which is used by the applicant of the present invention. According to the curves plotted by the triangles and the black circles, when the cell thickness is 4.2 μm, the transmittance is 5.8%. In Fig. 27, according to the curve plotted by the black circles, when the cell thickness is 4.2 μm, the transmittance is 6.2%. In Fig. 28, according to the curve plotted by the black circles, when the cell thickness is 4.2 μm, the transmittance is 6.9%. As described above, according to the present invention, it is possible to enhance

the transmittance.

[0055]

Fig. 29 is a cross-sectional view showing still another example of the liquid crystal cell with alignment division. Fig. 30 is a plan view showing the liquid crystal cell of Fig. 29. The liquid crystal cell 12 includes a pair of substrates 14 and 16 having electrodes and a liquid crystal layer 18 interposed between the pair of substrates. This liquid crystal cell 12 is used together with the first and second polarizers 20 and 22 and the first and second retardation plates 24 and 26 as shown in Fig. 1. In this example, the liquid crystal layer 18 is not limited to containing vertical alignment type liquid crystal, and may contain horizontal alignment type liquid crystal. It should be noted that the liquid crystal layer 18 is structured such that the state of alignment of liquid crystal molecules 18H changes, accompanied by a change in the polar angle and a change in the azimuth angle, upon application of voltage. It is not necessary for the substrates 14 and 16 to have the linear structures (ribs) 30 and 34 or the slits 38 for controlling the alignment.

[0056]

Fig. 31 is a view showing a liquid crystal cell having electrically conductive linear structures of a liquid crystal display device of a second embodiment of the present invention. The liquid crystal display device 10 includes a

liquid crystal cell 12 in which the liquid crystal layer 18 is interposed between first and second substrates 14 and 16, first and second polarizers 20 and 22, and first and second retardation plates 24 and 26 (see Fig. 1).

The first substrate 14 has linear structures 30, and the second substrate 16 has linear structures 34. The linear structures 30 and 34 are alternately arranged in parallel with each other as explained before (see, for example, Fig. 3). The linear structures 30 and 34 may be arranged in a grating pattern or a fishbone pattern.

[0057]

The linear structures 30 and 34 are electrically conductive structures. In Fig. 31, the linear structures 30 are formed of the same metallic material as that of the electrode 28 of the first substrate 14, and the linear structures 34 are formed of the same metallic material as that of the electrode 32 of the second substrate 16. For example, linear protrusions are formed on the substrates before the electrodes 28 and 32 are formed, and the electrodes 28 and 32 are formed thereon of ITO. Alternatively, the linear structures 30 and 34 are formed of an electrically conductive resin (such as a resin in which conductive grains of carbon or the like are mixed) on the electrodes 28 and 32. The height of the linear structures 30 and 34 is 0.1 μm to half of the cell thickness. In one example, the height of the linear

structure 30, 34 is 1.5 μm. A vertical alignment film is applied on the electrodes 28 and 32 and the linear structures 30 and 34.

[0058]

In the examples described so far, the linear structures 30 and 34 are formed of a dielectric substance. In the case where the linear structures 30 and 34 are formed of a dielectric substance, a part of voltage to be supplied between the electrodes 28 and 29 is absorbed by the dielectric substance, so that voltage applied to the liquid crystal is lowered by that level. Therefore, the liquid crystal molecules are insufficiently inclined when voltage is applied, and the transmittance is lowered. In this example, since the linear structures 30 and 34 are electrically conductive, a part of voltage to be supplied between the electrodes 28 and 32 is not absorbed. Thus, voltage applied to the liquid crystal is not lowered, the liquid crystal molecules are sufficiently inclined when voltage is applied, and the transmittance is not lowered.

[0059]

Fig. 32 is a view showing a state of alignment of the liquid crystal in the case where the liquid crystal cell shown in Fig. 31 is used. It can be understood that the liquid crystal molecules are sufficiently inclined when voltage is applied.

Fig. 33 is a view showing another example of the liquid crystal cell having electrically conductive linear structures. The first substrate 14 has linear structures 30 and slits 38, and the second substrate 16 has no linear structure or no slit. It should be noted that it is possible to adopt a structure in which the first substrate 14 has linear structures 30 and the second substrate 16 has slits 38.

[0060]

Fig. 34 is a view showing a state of alignment of the liquid crystal in the case where the liquid crystal cell shown in Fig. 33 is used. It can be understood that when voltage is applied, the liquid crystal molecules located close to the slit 38 are not sufficiently inclined, but the liquid crystal molecules located close to the linear structure 30 are sufficiently inclined. Even when the structure shown in Fig. 33 is adopted, it is possible to realize excellent alignment division, and further the transmittance can be enhanced.

[0061]

Fig. 35 is a view showing still another example of the liquid crystal cell having electrically conductive linear structures. The first substrate has linear structures 30M and linear structures 30D, and the second substrate 16 has no linear structure or no slit. The linear structures 30M are electrically conductive, and the linear structures 30D are dielectric. In the case where the linear structures 30M are

arranged at long intervals, the linear structure 30D is arranged between the linear structures 30M.

[0062]

Fig. 36 is a view showing a state of alignment of the liquid crystal in the case where the liquid crystal cell shown in Fig. 35 is used. It can be understood that when voltage is applied, the liquid crystal molecules located close to the linear structure 30D are not sufficiently inclined, but the liquid crystal molecules located close to the linear structure 30M are sufficiently inclined. Even when the structure shown in Fig. 35 is adopted, it is possible to realize excellent alignment division, and further the transmittance can be enhanced.

[0063]

Fig. 37 shows a liquid crystal display device of a third embodiment of the present invention. Fig. 37(A) shows a structure of the liquid crystal display device, Fig. 37(B) shows the contrast of the display when the image area is viewed in an oblique direction, and Fig. 37(C) shows the relation between applied voltage and the quantity of transmitting light. As shown in Fig. 37(A), the liquid crystal display device 10 includes a liquid crystal cell 12, first and second polarizers 20 and 22, and first and second retardation plates 24 and 26.

[0064]

Each of first and second retardation plates 24 and 26 respectively has an optical axis 24A or 26A in a plane parallel to the substrate surfaces and provides a retardation of substantially $\lambda/4$. The optical axis 24A of the first retardation plate 24 is perpendicular to the optical axis 26A of the second retardation plate 26. The polarizing axes 20A and 22A of the first and second polarizers 20 and 22 are arranged at an angle of 45° with respect to the optical axes 24A and 26A of the first and second retardation plates 24 and 26. The retardation in the plane of the first and second retardation plates 24 and 26 is not less than 120 nm and not more than 160 nm. It is preferable that the retardation in the plane of the first and second retardation plates 24 and 26 is not less than 130 nm and not more than 145 nm.

[0065]

The first polarizer 20 includes a polarizing layer (for example, PVA + iodine) 22p, and protective layers (for example, TAC; triacetyl cellulose) 20q and 20r which cover both sides of the polarizing layer 20p. In the same manner, the second polarizer 22 includes a polarizing layer (for example, PVA + iodine) 22p, and protective layers (for example, TAC; triacetyl cellulose) 22q and 22r which cover both sides of the polarizing layer 22p.

[0066]

The liquid crystal cell 12 has a structure in which the

liquid crystal layer 18 is interposed between the first and second substrates 14 and 16 as shown in Fig. 1. The liquid crystal layer 18 is formed of liquid crystal of a vertical alignment type. The liquid crystal cell includes structures or slits provided on or in the electrode of at least one of the substrates. The state of alignment of the liquid crystal molecules located on one side of the structure or slit is different from the state of alignment of the liquid crystal molecules located on the other side of the structure or slit. Any of the structures and slits explained above can be used.

[0067]

Fig. 38 shows an example of alignment division used in Fig. 37. The alignment division is realized by bent linear structures 30 provided on the electrode of the first substrate 14 and bent linear slits 38 provided in the electrode of the first substrate 14. In such alignment division, the liquid crystal molecules are aligned in four directions, as shown by arrows 18C, 18D, 18E and 18F. That is, alignment division with four divided regions is realized. In Fig. 38, gate bus lines 40, data bus lines 42, a TFT 44 and a storage capacitance electrode 46 are shown. The polarizers 20 and 22 are located in a cross arrangement.

[0068]

In the structure shown in Figs. 37(A) and 38, the contrast is as shown in Fig. 37(B). At this point, the

azimuth angle at which the contrast is kept for the widest range was rotated counterclockwise by about 30° from the vertical and horizontal directions. Concerning the viewing angle characteristic, a contrast of not less than 10 was obtained at an inclination angle of not less than 40°.

Fig. 39 shows a variation of the liquid crystal display device shown in Fig. 37. The liquid crystal display device 10 in Fig. 39 has substantially the same structure as that of the liquid crystal display device shown in Fig. 37, but a compensation film (for example, a TAC film) 48 having a negative retardation is stacked between the first retardation plate (λ/4) 24 and the liquid crystal cell 12, and a compensation film (for example, a TAC film) 50 having a negative retardation is stacked between the second retardation plate (λ/4) and the liquid crystal cell 12. By the stacking of the compensation films 48 and 50, a positive retardation of the liquid crystal layer 18 is compensated for, and a range in which the contrast is not less than 5 is enlarged (Fig. 39(B)). The viewing angle range in which the contrast is not less than 10 can be enlarged, and the contrast was kept to a level of not less than 10 up to an inclination angle of about 50°. It should be noted that in the T-V characteristic shown in Fig. 39(C), the brightness exhibits a strong tendency to decrease when voltage is increased and as a result, gradation inversion is likely to occur.

[0069]

Fig. 40 shows a case where the compensation films 48 and 50 having a negative retardation are not provided close to the liquid crystal cell 12 but are provided at distant positions from the liquid crystal cell 12. Although the compensation films 48 and 50 are added, the degree of improvement in the viewing angle characteristic was inferior to that of Fig. 39. Based on this, it was found that it is preferable to provide the compensation films 48 and 50 having a negative retardation close to the liquid crystal cell 12.

[0070]

Fig. 41 shows a variation of the liquid crystal display device shown in Fig. 37. The setting angles of the polarizers 20 and 22 were changed from those of Fig. 37. The polarizers 20 and 22 were set at azimuth angles of 45° and 135°, and the λ/4 plates 24 and 26 were located in a cross arrangement. In this case, the contrast curves show that the range in which the contrast is not less than 5 is enlarged as compared with the example of Fig. 37 (Fig. 41(B)). The T-V characteristic shows that the decrease of the brightness on the high voltage side is small and the gradation characteristic is excellent (Fig. 41(C)).

[0071]

Fig. 42 shows a variation of the liquid crystal display device shown in Fig. 31. TAC films as negative compensation

films 48 and 50 were stacked between the liquid crystal cell 12 and the λ/4 plates 24 and 26 respectively. Owing to this, a viewing angle range in which high contrast is obtained was enlarged (see the data shown in Figs. 41(B) and 42(B) for comparison). It should be noted that in T-V characteristic shows that the brightness is lowered on the high voltage side, and gradation inversion is likely to occur.

[0072]

Fig. 43 shows a variation of the liquid crystal display device shown in Figs. 37. The angles of the polarizers 20 and 22 were optimized, so that the viewing angle azimuth at which the contrast would be maximum was set at the vertical and horizontal directions. Calculation was made with an assumption that the retardation plates (λ/4) 24 and 26 are perfect uniaxial films. The direction of the absorbing axis 22A of the polarizer 22 on the incidence side was set at an azimuth angle of 145° to provide a crossed Nicols arrangement. The direction of the slow axis 26A of the retardation plate 26 close to the polarizer 22 was set at an azimuth angle of 10°, that is, at an angle of 45° with respect to the absorbing axis 22A of the polarizer 22 on the incidence side. The slow axis 24A of the retardation plate 24 paired with the retardation plate 26 was set at an azimuth angle of 100°, that is, at such an angle that the slow axes 24A and 26A of the retardation plates 24 and 26 were perpendicular to each other. The

compensation film 48 or 50 is not provided.

[0073]

Fig. 44 shows a variation of the liquid crystal display device shown in Fig. 43. The angles between the polarizers 20 and 22 and the retardation plates 24 and 26 shown in Fig. 43 were fixed, and TAC films as the negative compensation layers 48 and 50 were stacked between the liquid crystal cell 12 and the retardation plates 24 and 26 respectively. Owing to this, the viewing angle range was enlarged as compared with that in Fig. 43.

In the above, examples of alignment division with four divided regions have been described. Hereinafter, cases in which the present invention is applied to alignment division with two divided regions will be described. The division is made into upper and lower regions. Upon application of voltage, the liquid crystal molecules in the upper half of the pixel are inclined to the lower azimuth, and the liquid crystal molecules in the lower half of the pixel are inclined to the upper azimuth.

[0074]

Fig. 45 shows a variation of the liquid crystal display device shown in Fig. 37. The polarizers 20 and 22 were set in a cross arrangement, and the retardation plates 24 and 26 were set at azimuth angles of 45° and 135°.

Fig. 46 shows a variation of the liquid crystal display

device shown in Fig. 45. Fig. 37 shows alignment division with four divided regions, whereas Fig. 46 shows alignment division with two divided regions. Arrangements of the polarizers and films are the same as those shown in Fig. 37. TAC films as negative compensation layers 48 and 50 were stacked between the liquid crystal cell 12 and the retardation plates 24 and 26 respectively.

[0075]

Fig. 47 shows a variation of the liquid crystal display device shown in Fig. 37. The setting angles of the polarizers 20 and 22 and the retardation plates 24 and 26 were changed, so that the viewing angle characteristic was made symmetrical with respect to the vertical direction and the horizontal direction. The absorbing axis 22A of the polarizer 22 on the incidence side was set at an azimuth angle of 120°, the slow axis 26A of the retardation plate 26 close to the polarizer 22 was set at an azimuth angle of 75°, the slow axis 24A of the retardation plate 24 paired with the retardation plate 26 was set at an azimuth angle of -15°, and the absorbing axis 20A of the polarizer 20 on the outgoing side was set at an azimuth angle of 30°.

[0076]

Fig. 48 shows a variation of the liquid crystal display device shown in Fig. 47. TAC films as negative compensation layers 48 and 50 were stacked between the liquid crystal cell

12 and the retardation plates 24 and 26 respectively. The absorbing axis 22A of the polarizer 22 on the incidence side was set at an azimuth angle of 155°, the slow axis 26A of the retardation plate 26 close to the polarizer 22 was set at an azimuth angle of 20°, the slow axis 24A of the retardation plate 24 paired with the retardation plate 26 was set at an azimuth angle of 110°, and the absorbing axis 20A of the polarizer 20 on the outgoing side was set at an azimuth angle of 65°. Owing to this, although the symmetry was lost, a wide range of contrast was realized.

[0077]

Fig. 49 shows a variation of the liquid crystal display device shown in Fig. 37. A structure was devised so as to completely cancel the retardation of the liquid crystal layer 18, maximize the viewing angle range of the polarizers 20 and 22, and minimize leakage of light caused by the retardation plates 24 and 26. The structure will be explained from the polarizer 22 on the backlight side. The absorbing axis 22A of the polarizer 22 was set at an azimuth angle of 135°, and the slow axis 26A of the $\lambda/4$ plate 26 was then set at an azimuth angle of 0°. Then, the liquid crystal cell 12 of alignment division with four divided regions were set to be aligned at azimuth angles of 45°, 135°, 225° and 315°. Next, in order to completely cancel birefringence of the liquid crystal layer 18 of vertical alignment, an optical layer 52 having indices of

refraction in the form of a profile of a sitting cushion was set (Δnd which is the same as that of the liquid crystal layer). The slow axis 24A of the λ/4 plate 24 was then set at an azimuth angle of 90°, and then a uniaxial optical layer (represented as a rugby ball in the figure) 54 having a slow axis perpendicular to the substrates was set. Next, a film 56 providing a retardation of 140 nm was set as a uniaxial film in such a manner that a slow axis 56A thereof was set at an azimuth angle of 135°, and the absorbing axis 20A of the polarizer 20 was then set at an azimuth angle of 45°. In this case, the characteristic was symmetrical with respect to the vertical and horizontal directions, and further even at an oblique azimuth angle of 45°, the contrast was kept to a level of not less than 10 up to an inclination angle of 50°. It is preferable that the retardation of the optical layer 52, the profile of which is like a sitting cushion, is the same as the retardation of the liquid crystal layer 18. When the retardation was preferably set with a tolerance of ±10%, the range of good contrast was enlarged.

[0078]

Fig. 50 shows a variation of the liquid crystal display device shown in Fig. 49. This variation is different from the example shown in Fig. 49 in the setting angles of the polarizers 20 and 24. The structure will be explained from the polarizer 22 on the backlight side. The absorbing axis

22A of the polarizer 22 was set at an azimuth angle of 0°, and the slow axis of the λ/4 plate 26 was set at an azimuth angle of 45°. Then, the alignment directions of the liquid crystal cell 12 of alignment division with four divided regions were set at azimuth angles of 45°, 135°, 225° and 315°. Next, in order to completely cancel birefringence of the liquid crystal layer of vertical alignment, the optical layer 52 having indices of refraction in the form of a profile of a sitting cushion was set (Δnd which is the same as that of the liquid crystal layer). Next, the slow axis 24A of the λ/4 plate 24 was set at an azimuth angle of 135°. Next, the uniaxial optical layer (represented as a rugby ball in the figure) 54 having a slow axis perpendicular to the substrates was set. Next, the film 56 providing a retardation of 140 nm was set as a uniaxial film in such a manner that the slow axis 56A thereof was at an azimuth angle of 0°. Then, the absorbing axis 20A of the polarizer 20 was set at an azimuth angle of 90°. In this case, the azimuth angle at which the contrast was kept over the widest range was displaced from the vertical and horizontal directions and was an oblique azimuth angle of 45°, but the inclination angle at which the contrast was as low as 5 was 75° at the worst. Thus, a wide viewing angle range was realized.

[0079]

Fig. 51 shows a variation of the liquid crystal display

device shown in Fig. 37. In the example shown in Fig. 49, the alignment division is with four divided regions, whereas the alignment division is with two divided regions in this example. Basically, as opposed to the example shown in Fig. 49, the alignment division is made in two directions of 90° and 270°. The arrangements of the polarizers 20 and 22, the viewing angle improving films 52, 54 and 56, the λ/4 plates and the like are the same as those of the example shown in Fig. 49. The viewing angle characteristic of the contrast ratio is superior to that of the example shown in Fig. 49 with four divided regions. On the other hand, the T-V characteristic upon the application of voltage more largely undulates than that shown in Fig. 49. It is understood that the viewing angle characteristic when displaying middle tones is inferior. However, with alignment division with two divided regions, structures which are more easily produced can be considered than with alignment division with four divided regions.

[0080]

Fig. 52 shows a variation of the liquid crystal display device shown in Fig. 37. With respect to the example shown in Fig. 50, the setting angles of the polarizers 20 and 22, the compensation films 52, 54 and 56 and the like were not changed, and the alignment division of the liquid crystal cell 12 was made in two azimuth angles of 90° and 270°.

Fig. 53 shows a variation of the liquid crystal display device shown in Fig. 37. In the examples described so far, a uniaxial film, especially an optically uniaxial film, is used as the $\lambda/4$ plates 24 and 26. By contrast, in this example, a film providing a negative retardation (= (nx + ny)/2 - nz) of zero was used as the $\lambda/4$ plates 24 and 26. The viewing angle characteristic of the contrast ratio (Fig. 53(B)) shows no line of the contrast 10, and it is understood that an excellent viewing angle characteristic is realized within an inclination angle of 80° at all the azimuth angles. As this film providing a negative retardation of 0, NZ Film commercially available from Nitto Denko Corporation and a film commercially available under the name of SZ Film from Sumitomo Chemical Co, Ltd. were usable. When the negative retardation (= (nx + ny)/2 - nz) was set at 0 ± 20 nm, an especially wide viewing angle was realized. Further, the phase film 56 was set close to the polarizer 20 with the absorbing axis of the polarizer on one side and the slow axis of the phase film 56 being made perpendicular to each other. The value of the in-plane retardation of the phase film 56 was set to not less than 25 nm and not more than 70 nm when the phase film 56 was arranged close to both of the pair of polarizers, and to not less than 60 nm and not more than 160 nm (in this example, 140 nm) when the phase film 56 was arranged close to only one of the polarizers. Furthermore, the film 52 having a positive

optical anisotropy in a direction vertical to the substrates was stacked between the λ/4 plate 26 and the polarizer 22. The value of the retardation was set to not less than 80 nm and not more than 300 nm. The value was preferably set to 90 nm ± 10 nm. In this case, an especially wide viewing angle as shown in Fig. 53(B) was realized.

[0081]

Fig. 54 shows the relation between the alignment regulating directions for realizing the alignment division with four divided regions and the alignment directions of the liquid crystal molecules realized such alignment regulating directions. Solid line arrows 18I and 18J show azimuth angles to which the liquid crystal molecules on the TFT substrate side are to be tilted down, and dotted line arrows 18K and 18L show azimuth angles to which the liquid crystal molecules on the CF substrate side are to be tilted down. By these alignment regulating means, the action of tilting the liquid crystal molecules is exerted as shown by thick arrows 18C, 18D, 18E and 18F. The alignment azimuth angles of the liquid crystal obtained as a result of the alignment regulating azimuth angles are shown by thick arrow 18M. What is characteristic is that the directions of thick arrows 18C, 18D, 18E and 18F do not coincide with the directions of thick arrows 18M. In an intermediate region of the alignment regulating azimuth angles shown by thick arrows 18C, 18D, 18E

and 18F, the alignment of the liquid crystal molecules is directed to the two azimuth angles in which the liquid crystal molecules are to be equally divided. Therefore, in the entire pixel, the liquid crystal molecules entirely appear as being tilted toward the center of the pixel like the petals of tulip (or as if a flower of tulip were blooming outward).

[0082]

Fig. 55 shows a distribution of the quantity of transmitting light on the front face when the polarizers are set in a cross arrangement. As shown, a black cross region exists at the center of the pixel, and therefore it is impossible to obtain a bright display. When the $\lambda/4$ plates are set on both sides of the liquid crystal layer in this case, a bright display is realized.

As the method for alignment regulation shown in Fig. 54, optical alignment, rubbing or the like was used. As explained so far, by applying the present invention, it has been made possible to realize a bright display and also a liquid crystal display device having a wide viewing angle.

[0083]

Fig. 56 is a view showing a liquid crystal display device of a fourth embodiment of the present invention. Fig. 57 explains an action of a specific direction light scattering film shown in Fig. 5. Fig. 58 shows the alignment of liquid crystal molecules and the transmittance of a liquid crystal

display device with alignment division. In Fig. 56, the liquid crystal display device 10 includes a liquid crystal cell 12, first and second polarizers 20 and 22, a specific direction light scattering film 60, and a viewing angle improving film 62. The polarizers 20 and 22 include polarizing layers 20p and 22p and protective layers 20q, 20r, 22q and 22r as shown in Fig. 39. The protective layer 20r shown in Fig. 56 forms a part of the polarizer 20.

[0084]

The liquid crystal cell 12 has a structure in which the liquid crystal layer 18 is interposed between the first substrate 14 and the second substrate 16 as shown in Fig. 1. The liquid crystal layer 18 is formed of liquid crystal of a vertical alignment type. The liquid crystal cell 12 is subjected to alignment division. That is, the liquid crystal cell 12 includes structures or slits provided on or in the electrode of at least one of the substrates, and the state of alignment of liquid crystal molecules on one side of the structure or slit is different from the state of alignment of liquid crystal molecules on the other side of the structure or slit. Any of the structures and slits explained before can be used.

[0085]

Fig. 58 shows liquid crystal molecules 18c, 18d, 18e and 18f in four different states of alignment, and the relation

between the applied voltage and the quantity of transmitting light. Fig. 58(A) shows the states of alignment of the liquid crystal molecules 18c, 18d, 18e and 18f when, for example, a relatively low voltage V1 shown in Fig. 58(C) is applied and the image area is viewed in the normal direction. Fig. 58(B) shows the states of alignment of the liquid crystal molecules 18c, 18d, 18e and 18f when the same voltage V1 is applied and the image area is viewed in an oblique direction. In Fig. 58(C), curve TA is a T-V curve of the alignment of the liquid crystal molecule 18c in Fig. 58(B), curve TF is a T-V curve of the alignment of the liquid crystal molecule 18f in Fig. 58(B), and curve TN is a T-V curve of the average alignment of all the liquid crystal molecules in Fig. 58(A). As can be seen from Fig. 58(C), when the relatively low voltage V1 is applied and the image area is viewed in an oblique direction, the brightness is higher than that in the case where the image area is viewed in the normal direction. In the case where the relatively low voltage V1 is applied, it is intended to realize a relatively dark display in terms of the gradation or gray scale, but the display is whitish at certain viewing angles. This phenomenon may occasionally be conspicuous in the case where the viewing angle improving film 62 is included.

[0086]

The liquid crystal display device 10 shown in Fig. 56 is

made suitable for solving such a problem by being provided with the specific direction light scattering film 60. The specific direction light scattering film 60 scatters light significantly in one specific direction and relatively slightly in the other directions. As the specific direction light scattering film 60, for example, Nimisty of Sumitomo Chemical Co., Ltd. or the like is usable.

[0087]

Fig. 57(A) shows a case in which the liquid crystal display device 10 having no specific direction light scattering film 60 is viewed in an oblique direction, and Fig. 57(B) shows a case in which the liquid crystal display device 10 having the specific direction light scattering film 60 is viewed in an oblique direction. In Fig. 57(A), light which has obliquely transmitted through the liquid crystal cell 12 enters a viewer's eye, and the viewer may see a whitish display as described above. In Fig. 57(B), the specific direction light scattering film 60 has a property of causing light which has been incident thereon in the normal direction to be scattered in an oblique upper direction. Therefore, light which has transmitted through the liquid crystal cell 12 in the normal direction, and light which has obliquely transmitted through the liquid crystal cell 12, enter the viewer's eye, and the viewer sees a display which is close to the display of the image area viewed in the normal direction.

In order to reduce the parallax between the light which has transmitted through the liquid crystal cell 12 in the normal direction and the light which has obliquely transmitted through the liquid crystal cell 12, the specific direction light scattering film 60 is arranged close to the polarizer 20 on the light outgoing side and thus is preferable.

[0088]

The viewing angle improving film 62 is, for example, the retardation plate ($\lambda/4$ plate) 24 or 26 described in the above examples. The polarizers 20 and 22 and the retardation plates ($\lambda/4$ plate) 24 and 26 are combined with each other to create circularly polarized light so as to contribute to the enhancement of the brightness as described above. In Fig. 56, the viewing angle improving film 62 is provided only on one substrate 14, but of course, may also be provided on the other substrate 16. Further, the viewing angle improving film 62 may be one of the films 48, 50, 52, 54 and 56 shown in Figs. 39 to 53. That is, the viewing angle improving film 62 is formed of a uniaxial stretched film, a biaxial stretched film, a film having a negative retardation or the like.

[0089]

Fig. 59 is a view showing a variation of the liquid crystal display device shown in Fig. 56. In Fig. 56, the specific direction light scattering film 60 is arranged close to the polarizer 20 on the light outgoing side, and the

viewing angle improving film 62 is arranged close to the substrate 14. By contrast, in Fig. 59, the specific direction light scattering film 60 is arranged close to the substrate 14, and the viewing angle improving film 62 is arranged close to the polarizer 20 on the light outgoing side. The action of this example is the same as that of the example shown in Fig. 59.

[0090]

Concerning the position at which the film for scattering light in a specific direction is to be set, when the viewing angle improving film was arranged close to the liquid crystal layer and the light scattering film was arranged between this viewing angle improving film and the polarizing layer, an especially good viewing angle characteristic was obtained. Originally, the viewing angle improving film is provided for canceling the optical effect of the liquid crystal on light obliquely incident on the liquid crystal layer. However, when the light scattering film is arranged close to the liquid crystal layer, light perpendicularly incident on the liquid crystal layer is scattered and obliquely passes through the viewing angle improving film. In this case, although light perpendicularly incident on the liquid crystal layer is not subjected to any optical action by the liquid crystal layer, the viewing angle improving film exhibits an optical effect. That is, the viewing angle improving film acts so as to rather

cause leakage of light.

[0091]

Fig. 61 is a view showing a liquid crystal display device of a fifth embodiment of the present invention. Fig. 62 is a view explaining polarizing axes of the polarizers and optical axes of the retardation plates of the liquid crystal display device shown in Fig. 61. The liquid crystal display 10 includes a liquid crystal cell 12, first and second polarizers 20 and 22, and first and second retardation plates 24 and 26. Each of the first and second retardation plates 24 and 26 has an optical axis 24A or 26A in a plane parallel to surfaces of the substrate and provides a retardation of substantially $\lambda/4$. The optical axis 24A of the first retardation plate 24 is perpendicular to the optical axis 26A of the second retardation plate 26. The polarizing axes 20A and 22A of the first and second polarizers 20 and 22 are arranged at an angle of 45° with respect to the optical axes 24A and 26A of the first and second retardation plates 24 and 26. Voltage is applied between the electrodes 28 and 32.

[0092]

The liquid crystal cell 12 has a liquid crystal layer 18 interposed between the first substrate 14 and the second substrate 16. The liquid crystal layer 18 comprises liquid crystal droplets 70 dispersed in a resin 72. A liquid crystal display device having the liquid crystal layer 18 composed of

the liquid crystal droplets 70 and the resin 72 is referred to as a polymer dispersed liquid crystal display device. It should be noted that the present invention is not limited to a polymer dispersed liquid crystal display device and can be applied to other types of liquid crystal display devices having a liquid crystal layer 18 in which the liquid crystal droplets 70 coexist in the resin 72.

[0093]

Fig. 63 is a view showing a state of alignment of liquid crystal molecules in the liquid crystal droplet 70 when voltage is not applied. Liquid crystal molecules are aligned in all alignment directions. When voltage is applied in this state, the liquid crystal molecules are aligned in the liquid crystal droplet 70 perpendicularly to the substrate surface.

Fig. 64 is a view showing a display in the state of alignment of the liquid crystal molecules shown in Fig. 63 when voltage is not applied. The liquid crystal molecules are aligned substantially at random with respect to the substrate surface. Therefore, when the polarizers 20 and 22 are arranged in a crossed Nicols state and the λ/4 plates are provided, a white display is created.

[0094]

Fig. 65 is a view showing a display of a conventional liquid crystal display device having the polarizers 20 and 22 but no retardation plate 24 or 26. As shown in Fig. 63, the

liquid crystal molecules are aligned in all alignment directions in a liquid crystal droplet 70a, and the absorbing axes 20A and 22A of the polarizers 20 and 22 are arranged perpendicular to each other. Therefore, in a portion in which the liquid crystal molecules are aligned in the same direction as the absorbing axes 20A and 22A, the display becomes black. This is the same as the black lines 36 in Figs. 4 and 9.

[0095]

According to the present invention, it is possible to erase a black display portion shown in Fig. 65 and to realize a bright display as shown in Fig. 64 by providing the retardation plates 24 and 26.

In order to realize a polymer dispersed liquid crystal panel, a fluorine resin and an ultraviolet curable resin were mixed together (mixing ratio: about 8:2) such that the size of the liquid crystal droplets could be as large as possible. Liquid crystal having a positive dielectric constant anisotropy or a negative dielectric constant anisotropy is usable. In the case where liquid crystal having a positive dielectric constant anisotropy is used, it is desirable that the liquid crystal molecules lie down when voltage is not applied. Therefore, it is not unnecessary to apply an alignment film, and a mixture of the liquid crystal and the resin is injected between the substrates which have been washed. In the case where liquid crystal having a negative

dielectric constant anisotropy is used, the liquid crystal molecules lie down when voltage is applied. Therefore, when voltage is not applied, it is necessary to align the liquid crystal molecules in a vertical direction. Therefore, a polyimide film having a vertical alignment property is applied on the substrate.

[0096]

After the mixture of the liquid crystal and the resin was injected, ultraviolet ray was directed to cure the resin. During this process, the liquid crystal and the resin were separated from each other and the droplets 70 of the liquid crystal were formed.

Fig. 66 is a view showing a liquid crystal display device of a sixth embodiment of the present invention. Fig. 67 is a view explaining polarizing axes of the polarizers and optical axes of the retardation plates of the liquid crystal display device shown in Fig. 66. The liquid crystal display device 10 includes a liquid crystal cell 12, first and second polarizers 20 and 22, and first and second retardation plates 24 and 26. Each of the first and second retardation plates 24 and 26 has an optical axis 24A or 26A in a plane parallel to surfaces of the substrates and provides a retardation of substantially $\lambda/4$. The optical axis 24A of the first retardation plate 24 is perpendicular to the optical axis 26A of the second retardation plate 26. The polarizing axes 20A and 22A of the

first and second polarizers 20 and 22 are arranged at an angle of 45° with respect to the optical axes 24A and 26A of the first and second retardation plates 24 and 26. Voltage is applied between the electrodes 28 and 32.

[0097]

The liquid crystal cell 12 includes a liquid crystal layer 18 interposed between the first and second substrates 14 and 16. The liquid crystal layer 18 comprises liquid crystal 74 dispersed in a polymer network 76. A liquid crystal display device having the liquid crystal layer 18 composed of the liquid crystal 74 and the polymer network 76 is referred to as a polymer network liquid crystal display device. The liquid crystal is of a vertical aligning type liquid crystal having a negative dielectric constant anisotropy. The first substrate 14 is a color filter substrate, and the second substrate 16 is a TFT substrate.

[0098]

As described above, in the alignment division using the vertical alignment type liquid crystal and the linear structures 30 and 34 or the slits 38, the problem arises that when a part of the liquid crystal molecules and the polarizing axes of the polarizers coincide with each other upon application of voltage, the brightness is lowered. Retardation plates ($\lambda/4$) are provided so that the brightness can be enhanced. However, in the case where this technique is

applied to an image area, of a notebook personal computer or the like, which must be brighter, if there are provided linear structures 30 and 34 or slits 38 in the display region, the aperture ratio of the display region is decreased and a sufficiently high brightness cannot be provided. When the linear structures 30 and 34 or the slits 38 are provided only on the bus lines and the storage capacitance lines, the aperture ratio of the display region is increased and a sufficiently high brightness can be provided. However, in this case, an interval between the linear structures 30 and 34 or an interval between the linear structure 30 and the slit 38 is extended too large, and thus it takes a long time for the inclination of liquid crystals to be spread. As a result, the speed of response is lowered. The liquid crystal display device of this example is to solve this problem.

[0099]

The polymer network 76 is formed so as to regulate the pretilt of liquid crystal molecules of the liquid crystal 74 and the inclination direction of the liquid crystal molecules upon application of voltage (referred to as a "polymer stabilization"). The polymer network 76 is obtained as a result of a liquid crystal type or a non-liquid crystal type monomer being polymerized by ultraviolet rays or heat, and is solidified as a structure having a specific directivity during the process of polymerization. Accordingly, the polymer

network 76 aligns the liquid crystal molecules in the liquid crystal droplets 74 substantially in a vertical direction, with the liquid crystal molecules being pretilted. When voltage is applied, the liquid crystal molecules are inclined in the direction which is regulated by the polymer network 76 (direction in accordance with the pretilt) with a quick response.

[0100]

The monomer forming the polymer network 76 is made of an ultraviolet curable monomer or a thermosetting monomer. It is preferable that the monomer forming the polymer network 76 is a bifunctional acrylate or a mixture of a bifunctional acrylate and a monofunctional acrylate. It is preferable that the pretilt angle of the liquid crystal molecules regulated by the polymer network 76 is not less than 80°.

[0101]

Stabilization treatment of the polymer network 76 is conducted by a method shown in Fig. 68. While voltage is applied to the electrodes 28 and 32 of the liquid crystal cell 12 having a liquid crystal monomer inserted between the pair of substrates 14 and 16, the liquid crystal cell 12 is irradiated with ultraviolet (UV) to optically polymerize the liquid crystal monomer. Since polymerization is conducted while voltage is applied, the liquid crystal molecules are aligned toward the linear structures 30 and 34 or the slits 38

like when a liquid crystal display device with usual alignment division is being used.

[0102]

When the application of voltage which is conducted for stabilization treatment is stopped, the liquid crystal molecules are regulated by the solidified polymer and kept in a state of alignment of predetermined directions. In this way, the liquid crystal is pretilted. At this point, even if the linear strictures 30 and 34 or the slits 38 are not provided, the protrusions such as the bus lines and the storage capacitance electrodes act in an equivalent manner to that of the linear structures 30 and 34 or the slits 38. Therefore, the liquid crystal is pretilted. In this case, the speed of response is irrelevant to the behavior of the liquid crystal molecules. The liquid crystal molecules may take a relatively long period of time to be pretilted.

[0103]

The polymer network 76 is put into a solidified state, but does not become a completely solid body. Therefore, when voltage is applied upon the polymer network 76 while the liquid crystal display device is used, the liquid crystal molecules are inclined with respect to the substrate surfaces according to the pretilt. At this point, the entire liquid crystal molecules are already pretilted. Therefore, the speed of response is high.

The pretilt angle depends upon a quantity of monomer to be added, an optical polymerization initiator, a quantity of irradiated ultraviolet rays and an applied voltage. In order to keep the characteristics of the vertical alignment type liquid crystal, it is preferable that the pretilt angle is not less than 80°.

[0104]

Fig. 69 is a view showing the relation between the gradation and the speed of response when the liquid crystal display device is used. Curve X shows a speed of response in the case of the present invention, and curve Y shows a speed of response in the case where the polymer network 76 is not subjected to stabilization treatment. The liquid crystal monomer was of 1.8% by weight and the applied voltage for stabilization was 5.4 V. It is understood that according to the present invention, the responsiveness for display of the liquid crystal display device is considerably enhanced.

[0105]

Fig. 70 shows a structure for alignment division of the liquid crystal display device shown in Fig. 66. The color filter substrate 14 and TFT substrate 16 are provided with electrodes 28 and 32 and vertical alignment films 29 and 33. Although the alignment films are not shown in the above examples, the alignment films substantially the same as the vertical alignment films 29 and 33 shown in Fig. 70 are

provided in those examples. Further, the gate bus lines 40 and the storage capacitance electrodes 46 are shown in Fig. 70.

[0106]

In Fig. 70(A), neither the linear structures 30 or 34 nor the slits 38 are provided. In this case, during the stabilization treatment, the gate bus lines 40 and the storage capacitance electrodes 46 act as protruding structures. In Fig. 70(B), the linear structures 30 are provided only on the color filter substrate 14. The linear structures 30 are provided at positions corresponding to the storage capacitance electrodes 46, and therefore do not have an influence on the aperture ratio of the display region.

[0107]

In Fig. 70(C), the linear structures 30 are provided on the color filter substrate 14, and the linear structures 34 are provided on the TFT substrate 16. The linear structures 30 are provided at positions corresponding to the storage capacitance electrodes 46, and the linear structures 34 are provided at positions corresponding to the gate bus lines 40. Therefore, neither linear structures 30 nor 34 affect the aperture ratio of the display region.

In Fig. 70(D), the linear structures 30 are provided on the color filter substrate 14, and the slits 38 are provided in the TFT substrate 16. The linear structures 30 and the

slits 38 are arranged at intervals shorter than those of the example shown in Fig. 70(C). For example, the linear structures 30 and the slits 38 can be arranged with the pattern shown in Fig. 38 or any other patterns.

[0108]

[Effect of the Invention]

As explained above, according to the present invention, a liquid crystal display device by which an excellent image area can be viewed over a wide viewing angle and which provides high brightness can be obtained.

[Brief Description of the Drawings]

[Fig. 1]

Fig. 1 is a schematic view showing a liquid crystal display device of a first embodiment of the present invention.

[Fig. 2]

Fig. 2 is a schematic cross-sectional view showing the liquid crystal cell shown in Fig. 1.

[Fig. 3]

Fig. 3 is a schematic plan view showing linear structures and liquid crystal molecules of the liquid crystal cell shown in Fig. 2.

[Fig. 4]

Fig. 4 is a view showing portion A of Fig. 3 in detail.

[Fig. 5]

Fig. 5 is a schematic cross-sectional view showing a

variation of the liquid crystal cell shown in Fig. 2.

[Fig. 6]

Fig. 6 is a schematic plan view of the liquid crystal cell shown in Fig. 5.

[Fig. 7]

Fig. 7 is a schematic cross-sectional view showing a variation of the liquid crystal cell.

[Fig. 8]

Fig. 8 is a schematic plan view showing the liquid crystal cell shown in Fig. 7.

[Fig. 9]

Fig. 9 is a view showing a portion of Fig. 8 in detail.

[Fig. 10]

Fig. 10 is a schematic cross-sectional view showing a variation of the liquid crystal cell.

[Fig. 11]

Fig. 11 is a schematic plan view showing the liquid crystal cell shown in Fig. 9.

[Fig. 12]

Fig. 12 is a schematic cross-sectional view showing a variation of the liquid crystal cell.

[Fig. 13]

Fig. 13 is a schematic plan view showing the liquid crystal cell in Fig. 11.

[Fig. 14]

Fig. 14 is a view showing portion A of Fig. 13 in detail.

[Fig. 15]

Fig. 15 shows an action of a retardation plate (λ/4); (A) shows the relation among the polarizing axes of the first and second polarizers, the optical axes of the first and second retardation plates, and the director of the liquid crystal layer; and (B) shows a state of light passing through the first polarizer, the first retardation plate, the liquid crystal layer, the second retardation plate and the second polarizer.

[Fig. 16]

Fig. 16 shows polarized light passing through the liquid crystal layer in the case where the retardation of the liquid crystal layer is λ/2.

[Fig. 17]

Fig. 17 shows polarized light passing through the liquid crystal layer and the retardation plate (λ/4) in the case where the retardation of the liquid crystal layer is λ/4.

[Fig. 18]

Fig. 18 is a view showing an example of an image area of a liquid crystal display device in which conventional alignment division is conducted.

[Fig. 19]

Fig. 19 is a view showing an example of an image area of a liquid crystal display device in which alignment division is

conducted and the first and second retardation plates are provided.

[Fig. 20]

Fig. 20 shows the relation between the applied voltage and the transmittance and the relation between the transmittance and the speed of response of liquid crystal display devices in which alignment division is conducted according to the conventional manner and according to the present invention.

[Fig. 21]

Fig. 21 shows another example of alignment division.

[Fig. 22]

Fig. 22 shows still another example of alignment division.

[Fig. 23]

Fig. 23 shows still another example of alignment division.

[Fig. 24]

Fig. 24 shows still another example of alignment division.

[Fig. 25]

Fig. 25 is a view showing the relation between the attained transmittance and the rise time with the alignment division shown in Fig. 24.

[Fig. 26]

Fig. 26 is a view showing the relation between the cell thickness and the transmittance with alignment division provided by parallel linear structures.

[Fig. 27]

Fig. 27 is a view showing the relation between the cell thickness and the transmittance with grating pattern alignment division.

[Fig. 28]

Fig. 28 is a view showing the relation between the cell thickness and the transmittance with fishbone pattern alignment division.

[Fig. 29]

Fig. 29 is a cross-sectional view showing another example of the liquid crystal cell.

[Fig. 30]

Fig. 30 is a plan view showing the liquid crystal cell in Fig. 29.

[Fig. 31]

Fig. 31 is a cross-sectional view showing a liquid crystal cell having electrically conductive linear structures of a liquid crystal display of a second embodiment of the present invention.

[Fig. 32]

Fig. 32 is a view showing a state of alignment of liquid crystal in the case where the liquid crystal cell in Fig. 31

is used.

[Fig. 33]

Fig. 33 is a cross-sectional view showing another example of the liquid crystal cell having electrically conductive linear structures.

[Fig. 34]

Fig. 34 is a view showing a state of alignment of liquid crystal in the case where the liquid crystal cell shown Fig. 33 is used.

[Fig. 35]

Fig. 35 is a cross-sectional view showing another example of the liquid crystal cell having electrically conductive linear structures.

[Fig. 36]

Fig. 36 is a view showing a state of alignment of liquid crystal in the case where the liquid crystal cell shown in Fig. 33 is used.

[Fig. 37]

Fig. 37 shows a liquid crystal display device of a third embodiment of the present invention.

[Fig. 38]

Fig. 38 is a view showing an example of alignment division used in Fig. 37.

[Fig. 39]

Fig. 39 shows a variation of the liquid crystal display

device shown in Fig. 37.

[Fig. 40]

Fig. 40 shows a variation of the liquid crystal display device shown in Fig. 37.

[Fig. 41]

Fig. 41 shows a variation of the liquid crystal display device shown in Fig. 37.

[Fig. 42]

Fig. 42 shows a variation of the liquid crystal display device shown in Fig. 37.

[Fig. 43]

Fig. 43 shows a variation of the liquid crystal display device shown in Fig. 37.

[Fig. 44]

Fig. 44 shows a variation of the liquid crystal display device shown in Fig. 37.

[Fig. 45]

Fig. 45 shows a variation of the liquid crystal display device shown in Fig. 37.

[Fig. 46]

Fig. 46 shows a variation of the liquid crystal display device shown in Fig. 37.

[Fig. 47]

Fig. 47 shows a variation of the liquid crystal display device shown in Fig. 37.

[Fig. 48]

Fig. 48 shows a variation of the liquid crystal display device shown in Fig. 37.

[Fig. 49]

Fig. 49 shows a variation of the liquid crystal display device shown in Fig. 37.

[Fig. 50]

Fig. 50 shows a variation of the liquid crystal display device shown in Fig. 37.

[Fig. 51]

Fig. 51 shows a variation of the liquid crystal display device shown in Fig. 37.

[Fig. 52]

Fig. 52 shows a variation of the liquid crystal display device shown in Fig. 37.

[Fig. 53]

Fig. 53 shows a variation of the liquid crystal display device shown in Fig. 37.

[Fig. 54]

Fig. 54 shows a variation of the liquid crystal display device shown in Fig. 37.

[Fig. 55]

Fig. 55 is a view showing a distribution of a quantity of transmitting light on the front surface when the polarizers are set in a cross arrangement in the liquid crystal display

shown in Fig. 54.

[Fig. 56]

Fig. 56 is a view showing a liquid crystal display device of a fourth embodiment of the present invention.

[Fig. 57]

Fig. 57 explains an action of a specific direction light scattering film shown in Fig. 56.

[Fig. 58]

Fig. 58 shows the alignment and the transmittance of liquid crystal molecules of a liquid crystal display device in which alignment division is conducted.

[Fig. 59]

Fig. 59 is a view showing a variation of the liquid crystal display device shown in Fig. 56.

[Fig. 60]

Fig. 60 is a view showing a variation of the liquid crystal display device shown in Fig. 56.

[Fig. 61]

Fig. 61 is a view showing a liquid crystal display device of a fifth embodiment of the present invention.

[Fig. 62]

Fig. 62 is a view explaining the polarizing axes of the polarizers and the optical axes of the retardation plates of the liquid crystal display device shown in Fig. 61.

[Fig. 63]

Fig. 63 is a view showing a state of alignment of liquid crystal molecules in liquid crystal droplets shown in Fig. 63.

[Fig. 64]

Fig. 64 is a view showing a display in the state of alignment of liquid crystal molecules shown in Fig. 63.

[Fig. 65]

Fig. 65 is a view showing a display of a conventional liquid crystal display device.

[Fig. 66]

Fig. 66 is a view showing a liquid crystal display of a sixth embodiment of the present invention.

[Fig. 67]

Fig. 67 is a view explaining the polarizing axes of the polarizers and the optical axes of the retardation plates of the liquid crystal display device shown in Fig. 66.

[Fig. 68]

Fig. 68 is a view showing stabilization treatment performed on the liquid crystal cell shown in Fig. 66.

[Fig. 69]

Fig. 69 is a view showing the relation between the gradation and the speed of response when a liquid crystal display device is used.

[Fig. 70]

Fig. 70 shows a structure for alignment division of the liquid crystal display device shown in Fig. 66.

[Description of the Reference Numerals]

10 ... Liquid crystal display device

12 ... Liquid crystal cell

14, 16 ... Substrate

18 ... Liquid crystal layer

20, 22 ... Polarizer

24, 26 ... Retardation plate

30, 34 ... Linear structure

38 ... Slit

48, 50 ... Compensation film

52, 54, 56 ... Optical layer

60 ... Specific direction light scattering film

62 ... Viewing angle improving film

70 ... Liquid crystal droplet

72 ... Resin

74 ... Liquid crystal

76 ... Polymer network

[Name of the Document] ABSTRACT

[Abstract]

[Problem] Relates to a liquid crystal display device, and has an object of providing a liquid crystal display device by which an excellent image area can be viewed over a wide viewing angle and which provides high brightness.

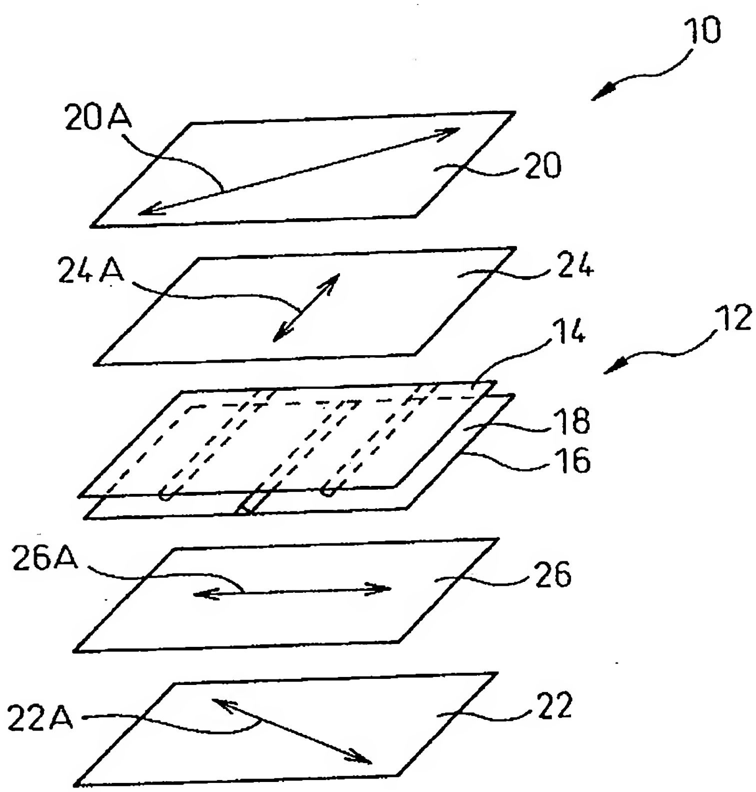
[Means for Solving the Problems] Includes a liquid crystal cell 12 comprising a liquid crystal layer interposed between a pair of substrates; first and second polarizers 20 and 22 arranged on either side of the liquid crystal cell; and a first retardation plate 24 arranged between the liquid crystal cell and the first polarizer and a second retardation plate 26 arranged between the liquid crystal cell and the second polarizer. Each of the first and second retardation plates has an optical axis 24A or 26A in a plane parallel to surfaces of the substrates and provides a retardation of substantially $\lambda/4$. An optical axis 20A, 22A of the first retardation plate is perpendicular to an optical axis of the second retardation plate. Polarizing axes of the first and second polarizers are arranged at an angle of 45° with respect to the optical axes of the first and second retardation plates. The liquid crystal cell 12 is structured such that a state of alignment of liquid crystal molecules changes, accompanied by a change in a polar angle and/or a change in an azimuth angle, upon application of voltage.

[Selected Figure] Fig. 1

[Name of Document] Drawings

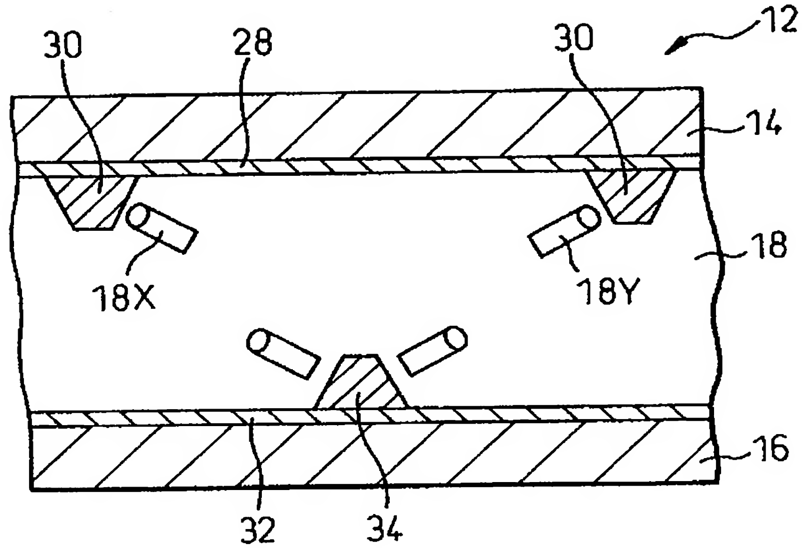
[Fig.1]

図 1



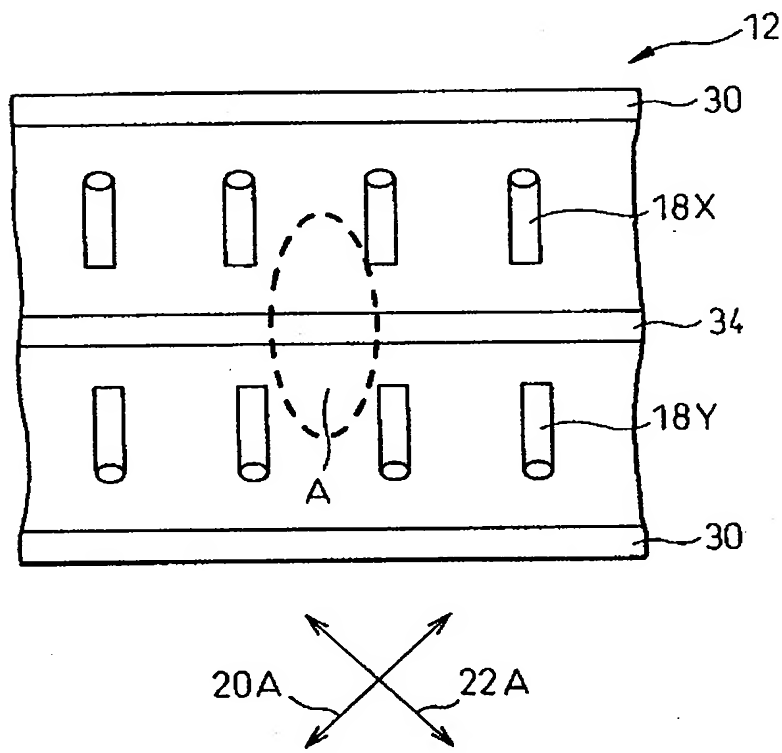
[Fig.2]

図 2



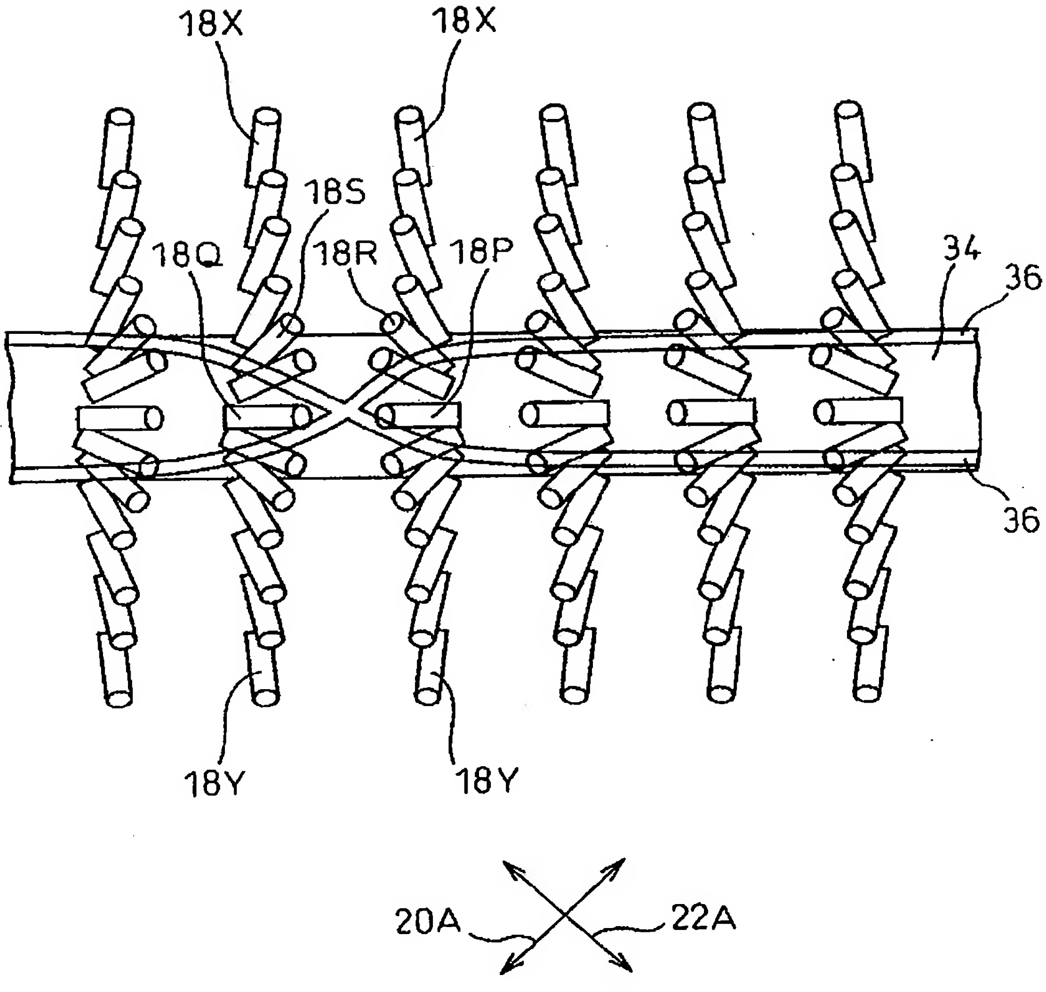
[Fig.3]

図 3



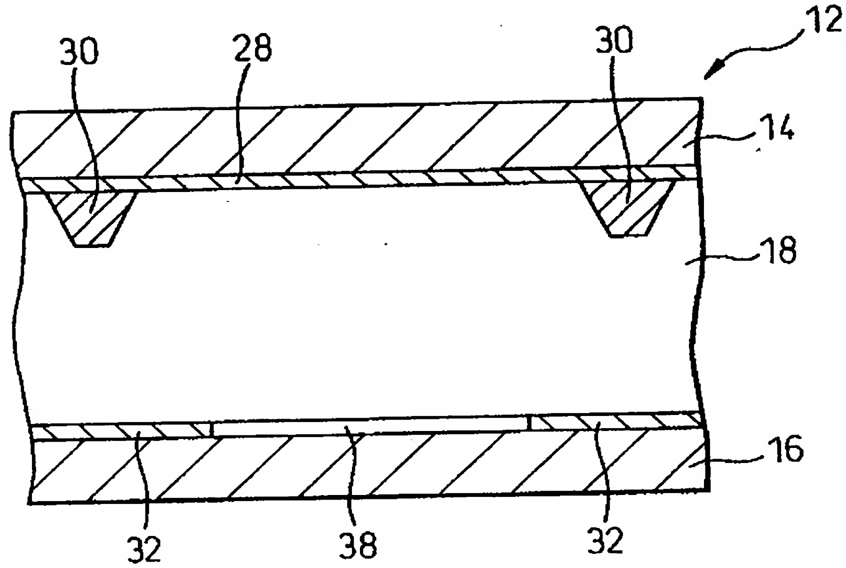
[Fig.4]

図 4



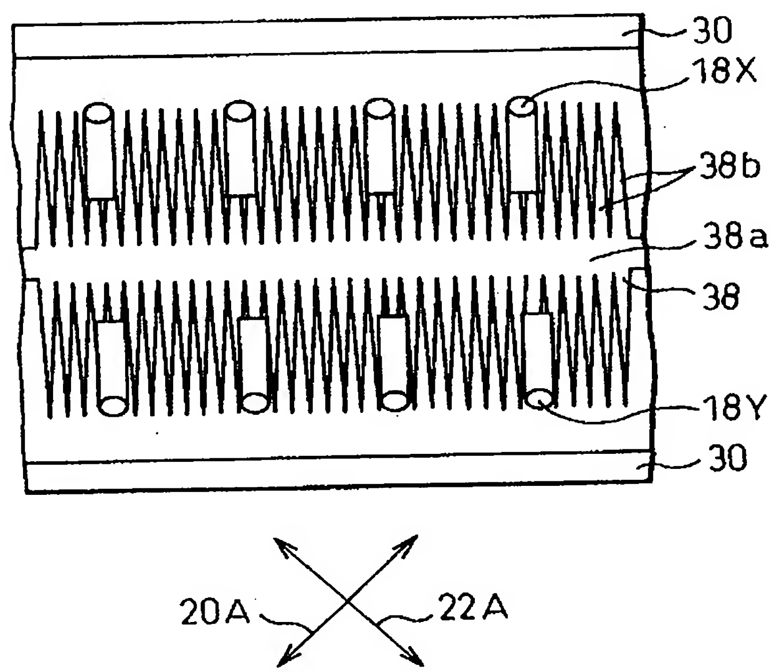
[Fig.5]

図 5



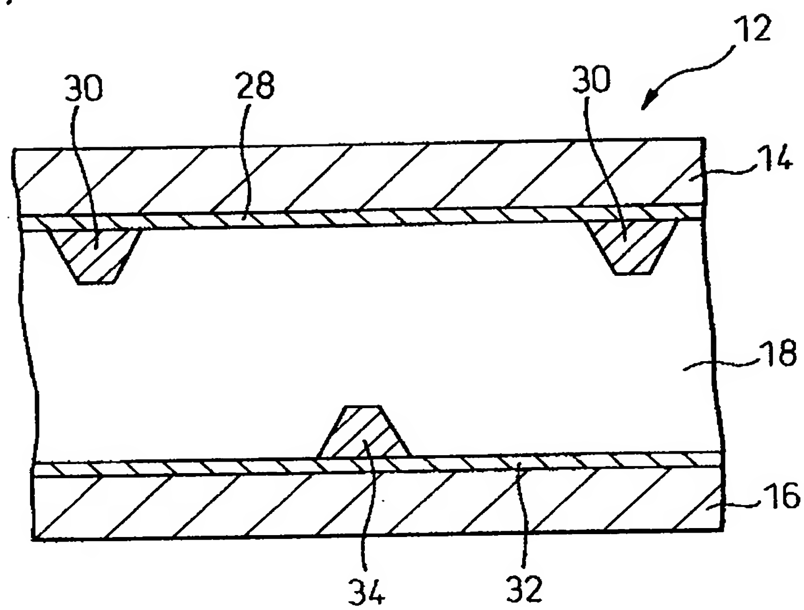
[Fig.6]

図 6



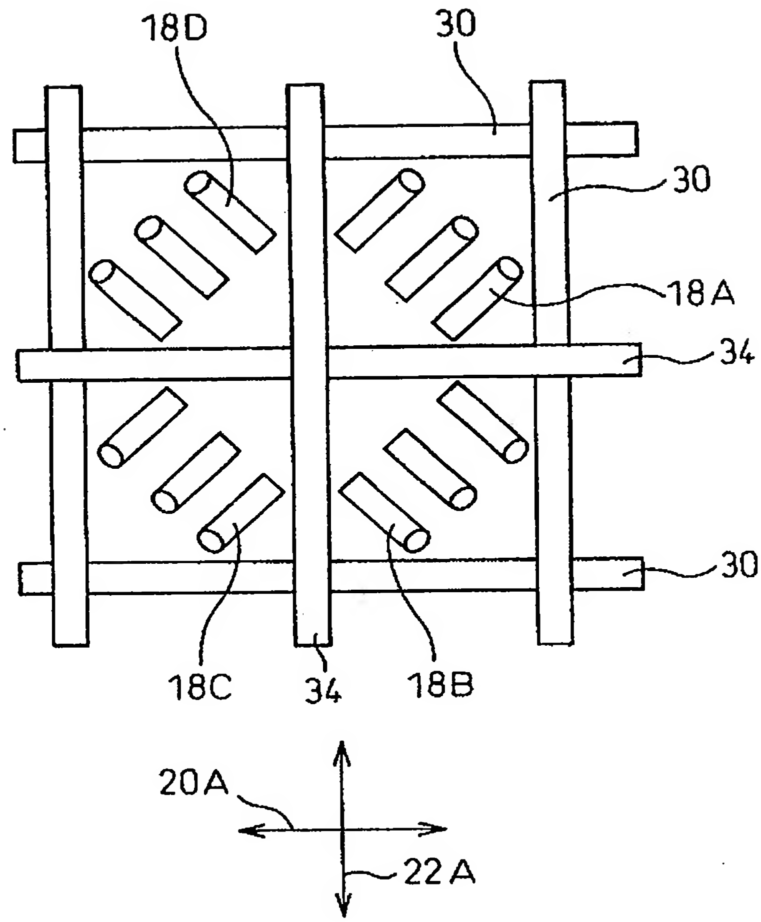
[Fig.7]

図 7



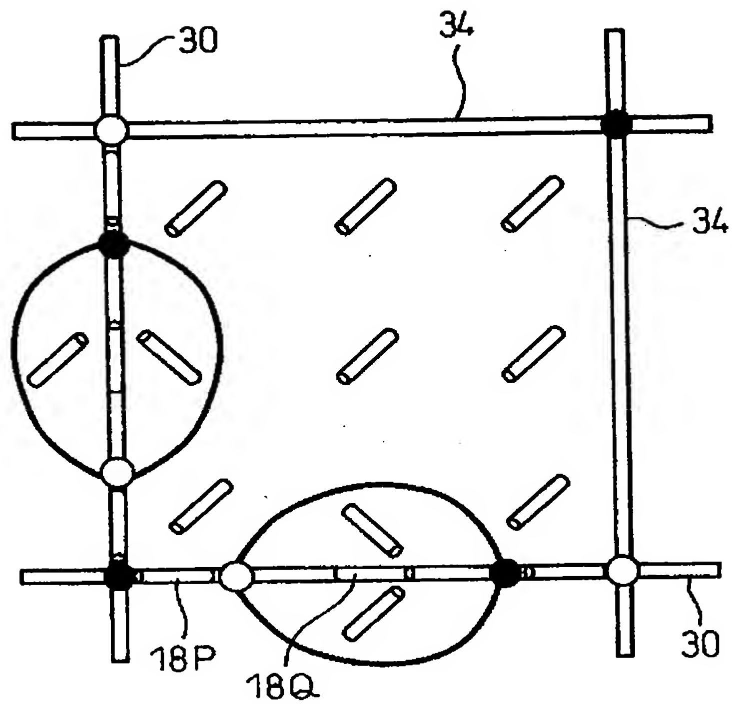
[Fig.8]

図 8



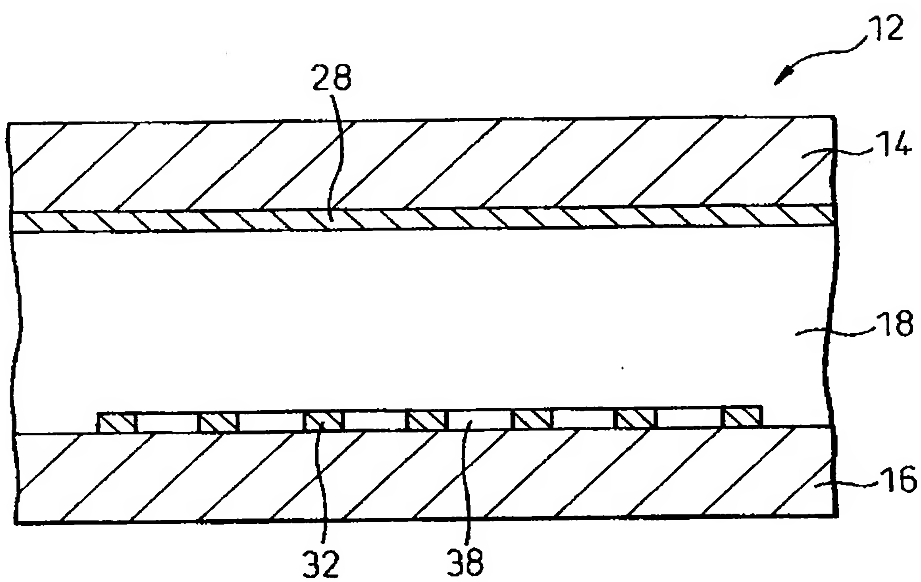
[Fig.9]

図 9



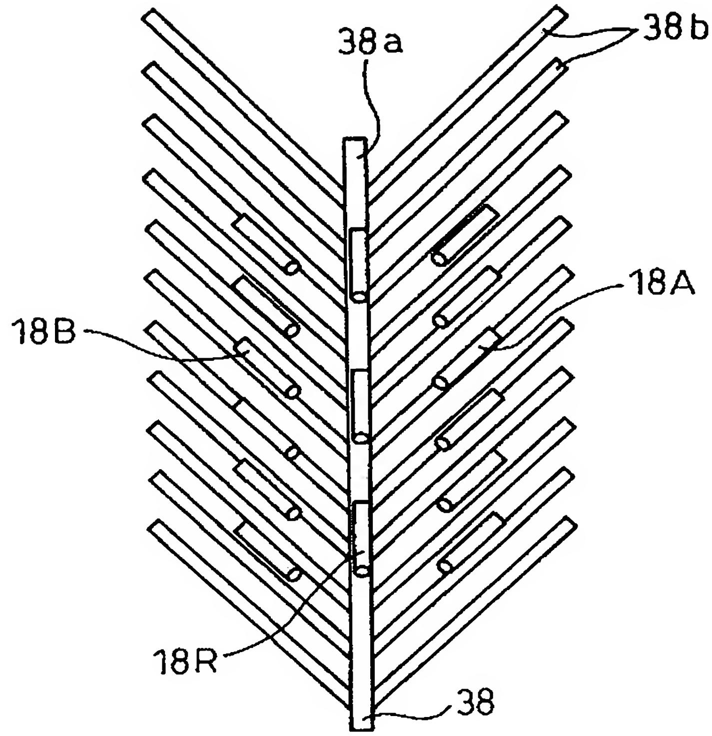
[Fig.10]

図 10



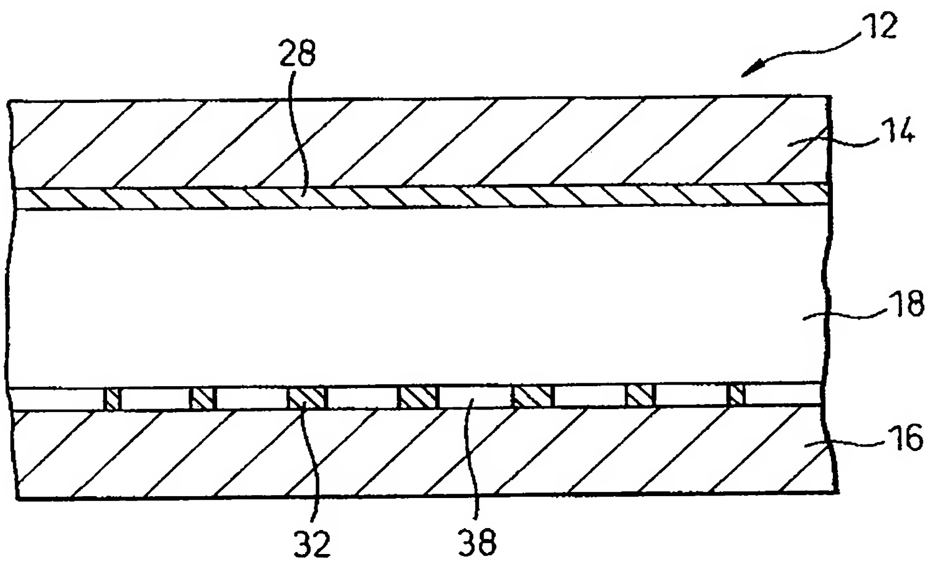
[Fig.11]

図11



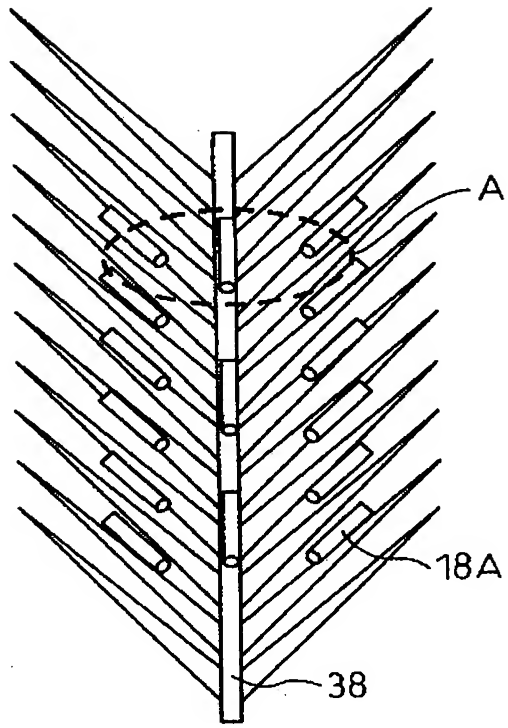
[Fig.12]

図12



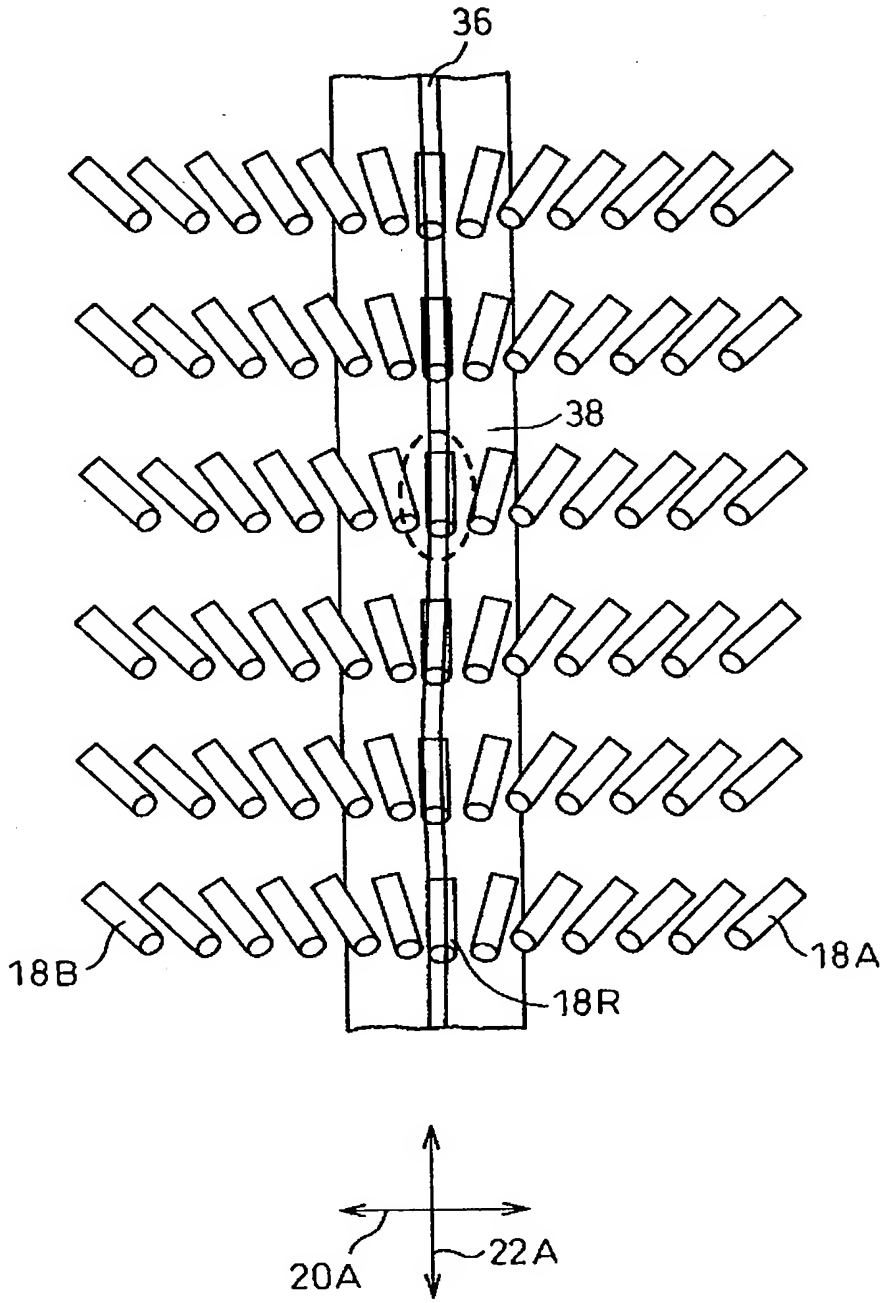
[Fig.13]

図 13

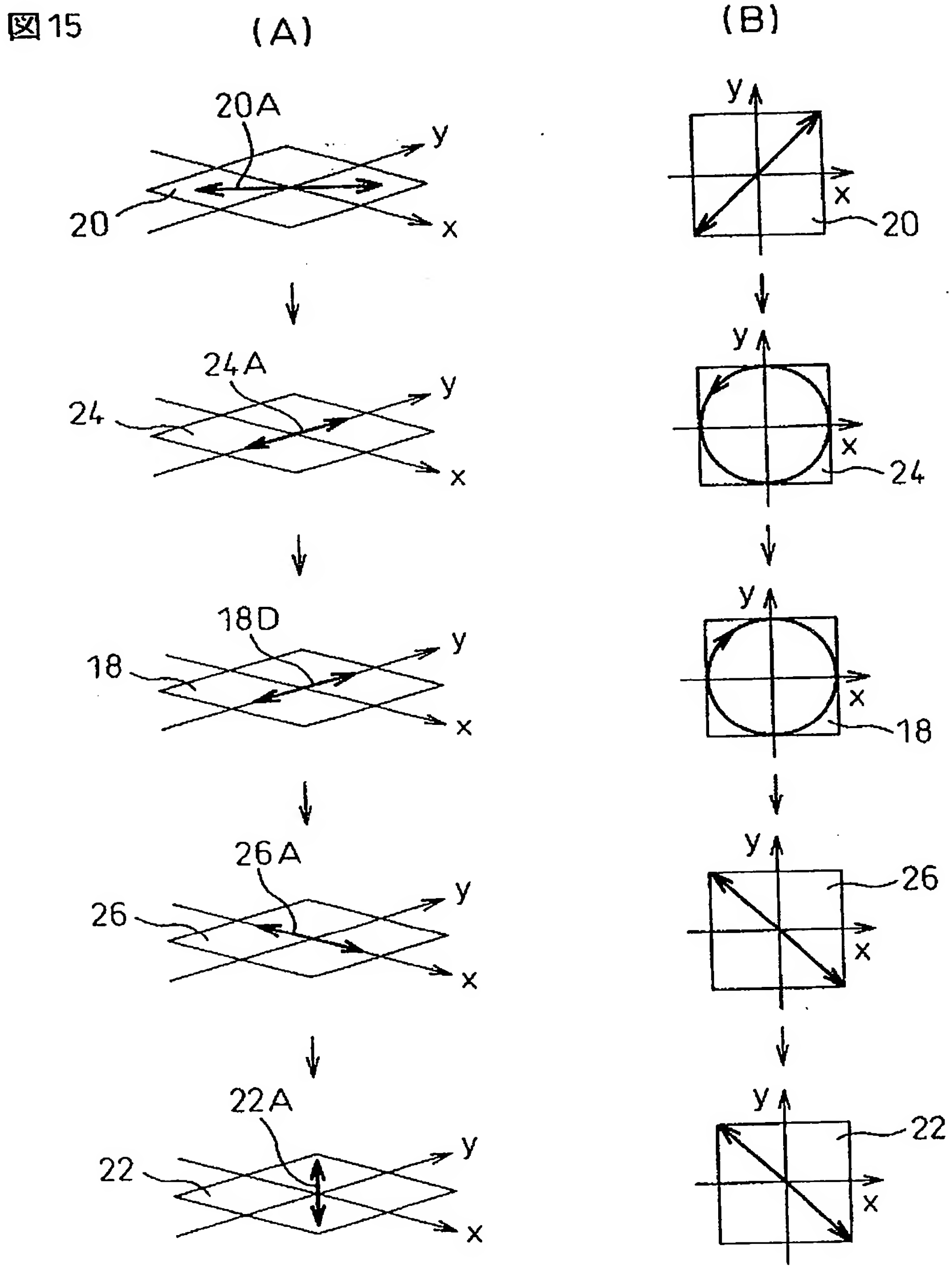


[Fig.14]

図14

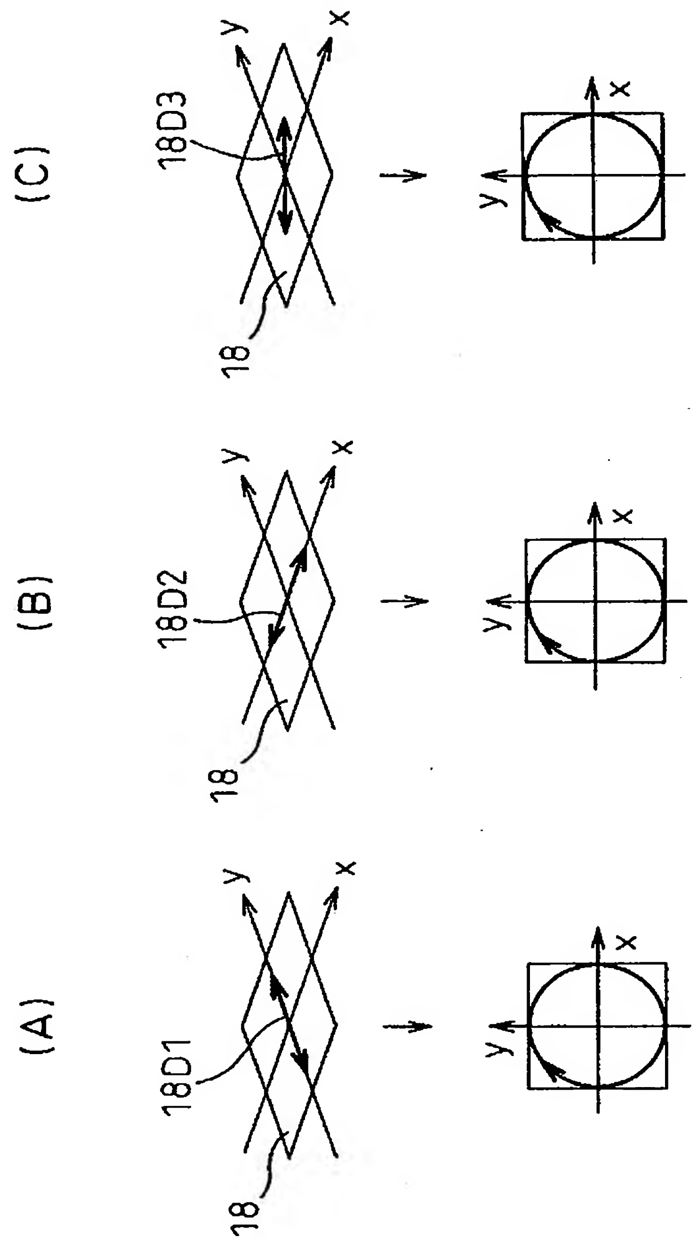


[Fig.15]



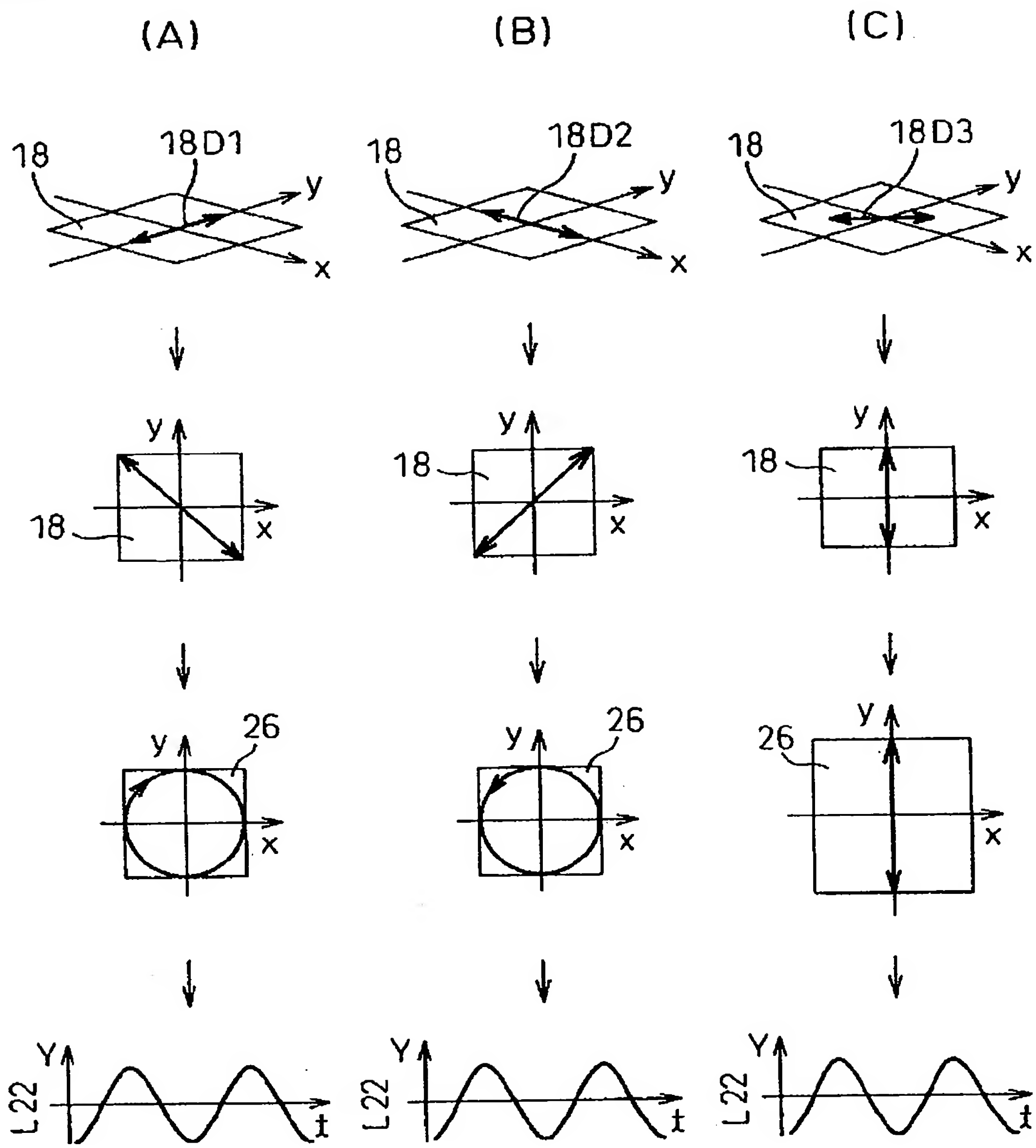
[Fig.16]

図16



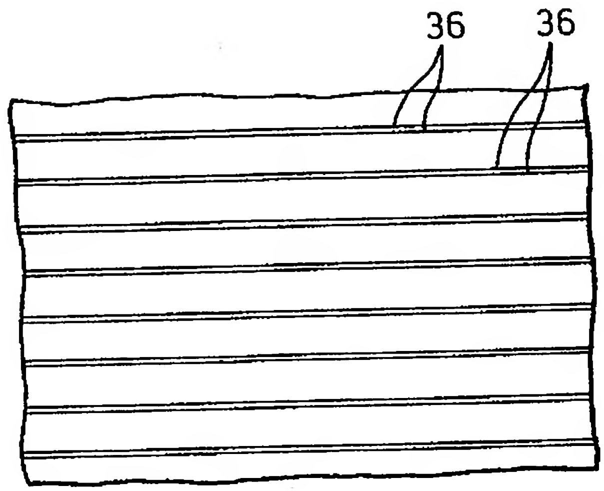
[Fig.17]

図17



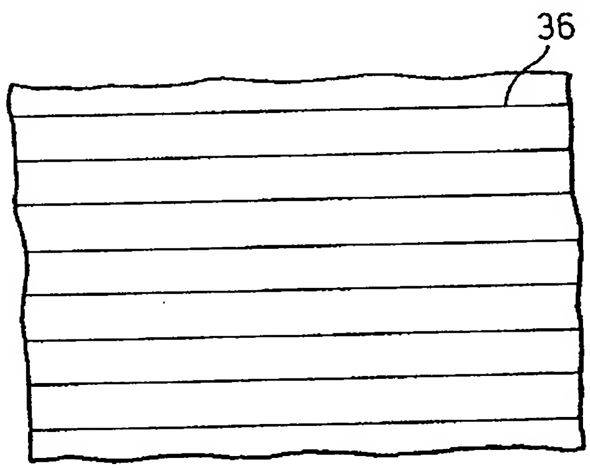
[Fig.18]

図18



[Fig.19]

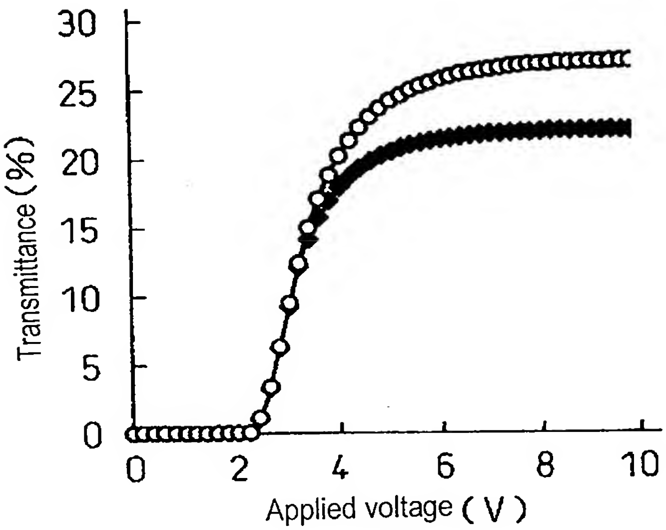
図19



[Fig.20]

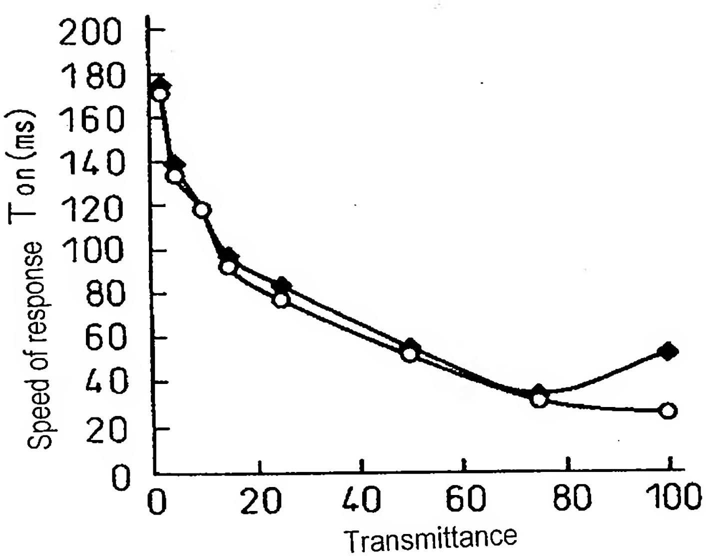
図 20

(A)



30
25
20
15
10
5
0
Transmittance (%)
0
2
4
6
8
10
Applied voltage (V)

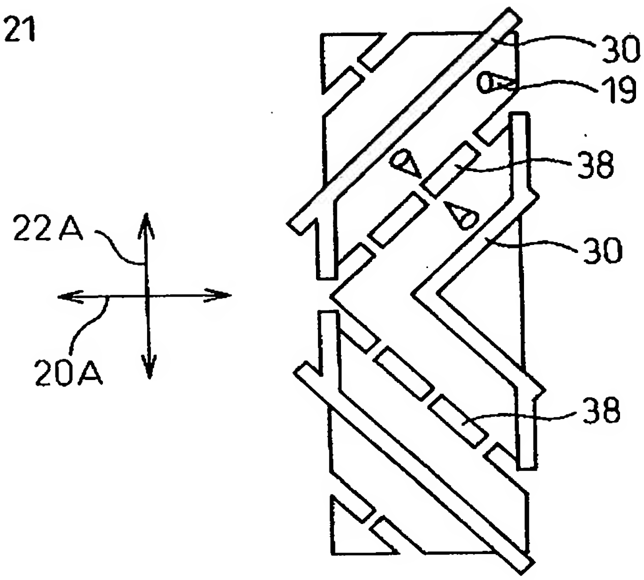
(B)



200
180
160
140
120
100
80
60
40
20
0
Speed of response T on (ms)
0
20
40
60
80
100
Transmittance

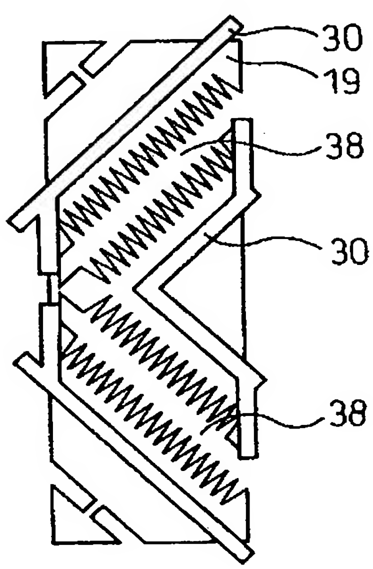
[Fig.21]

図 21



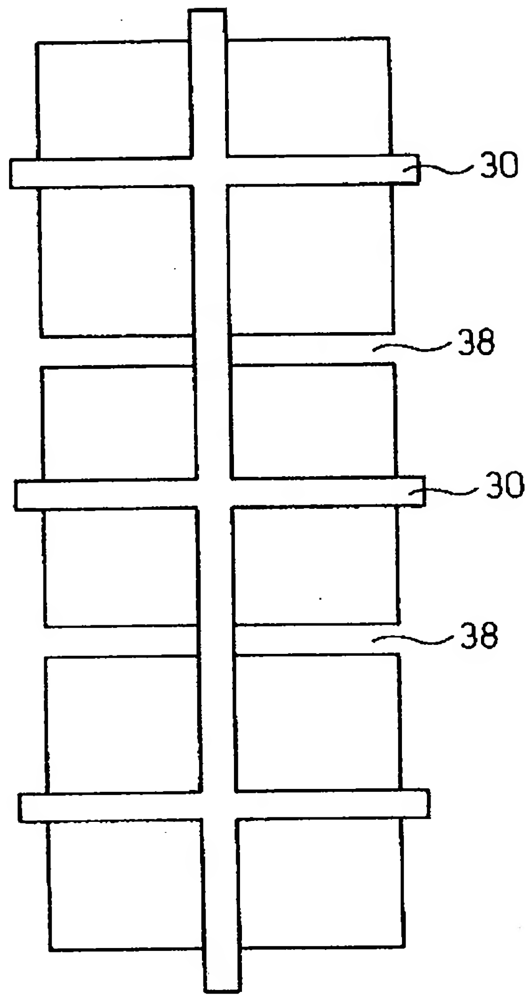
[Fig.22]

図 22



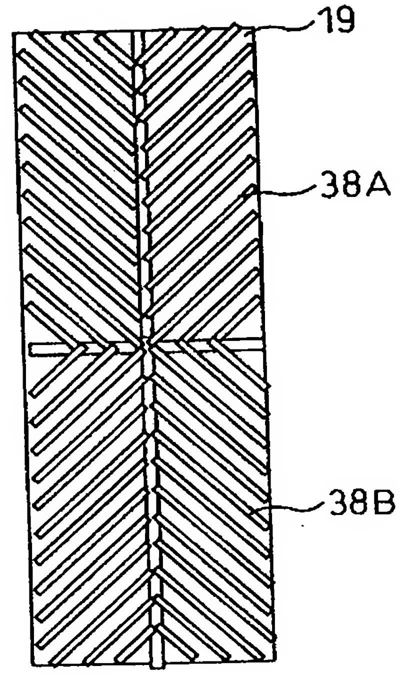
[Fig.23]

図 23



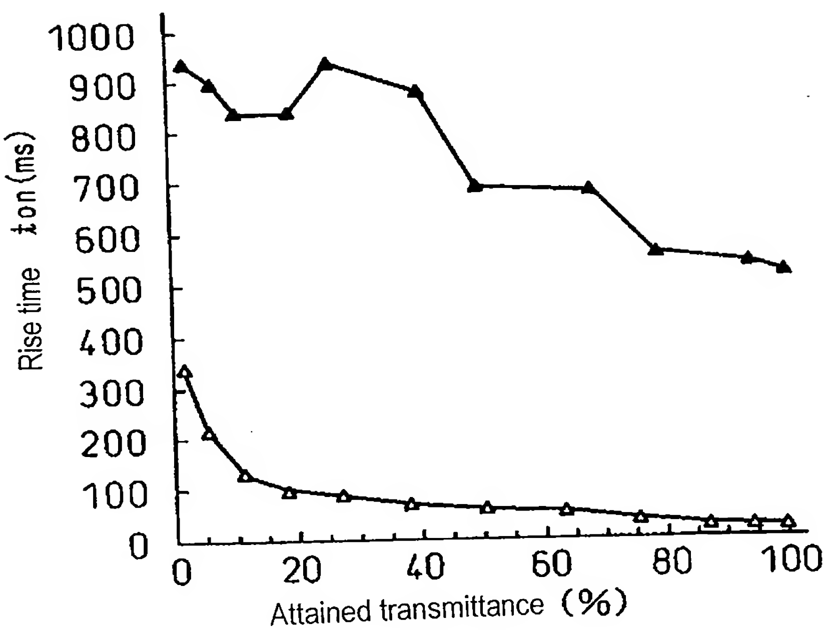
[Fig.24]

図 24



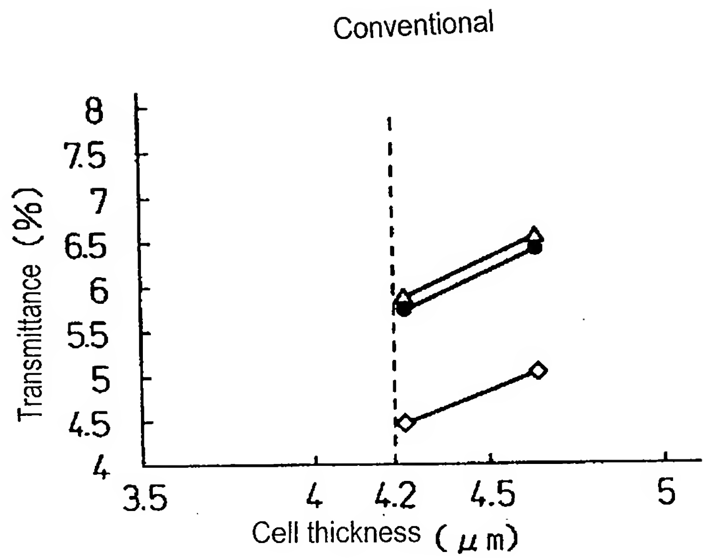
[Fig.25]

図 25



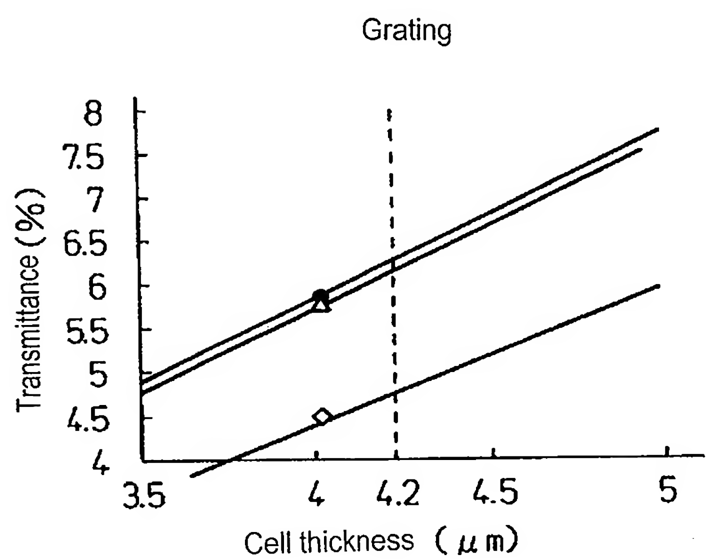
[Fig.26]

図 26



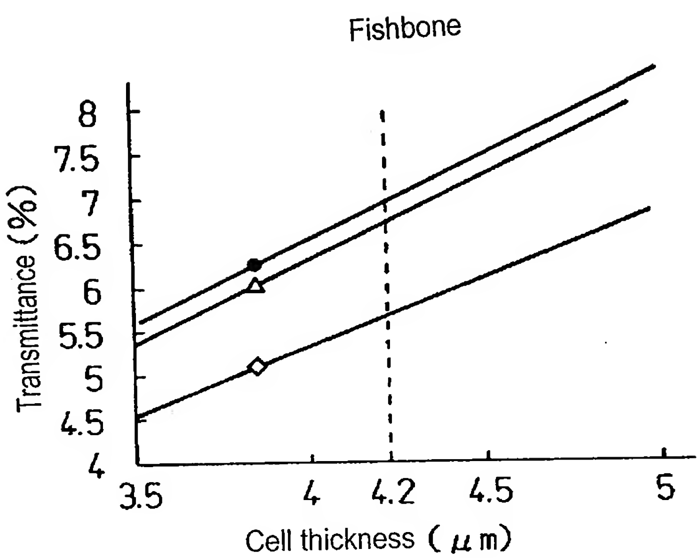
[Fig.27]

図 27



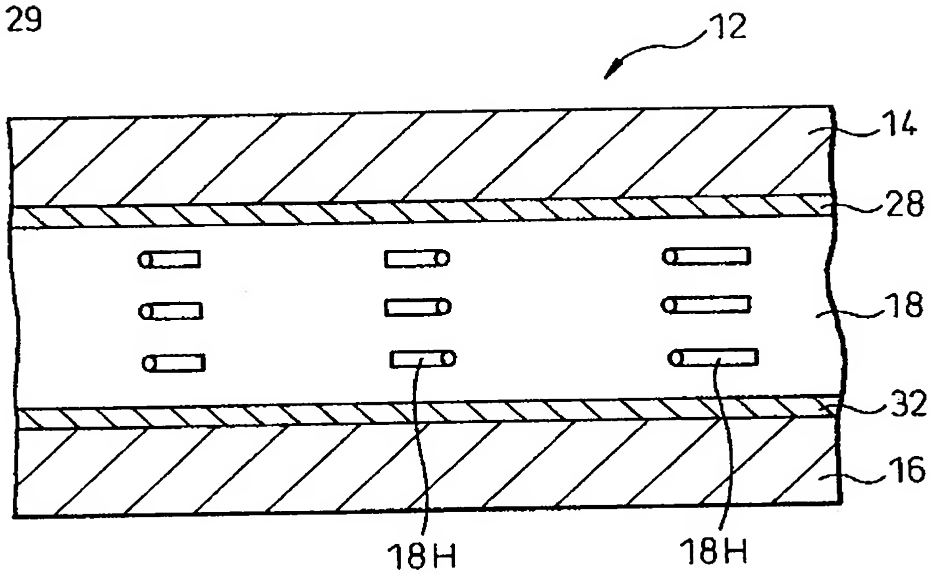
[Fig.28]

図28



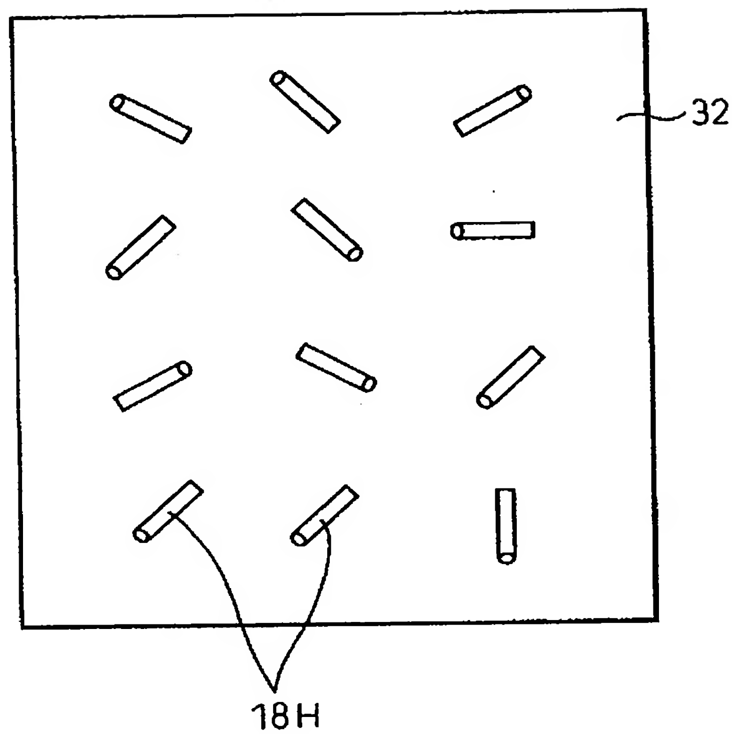
[Fig.29]

図 29



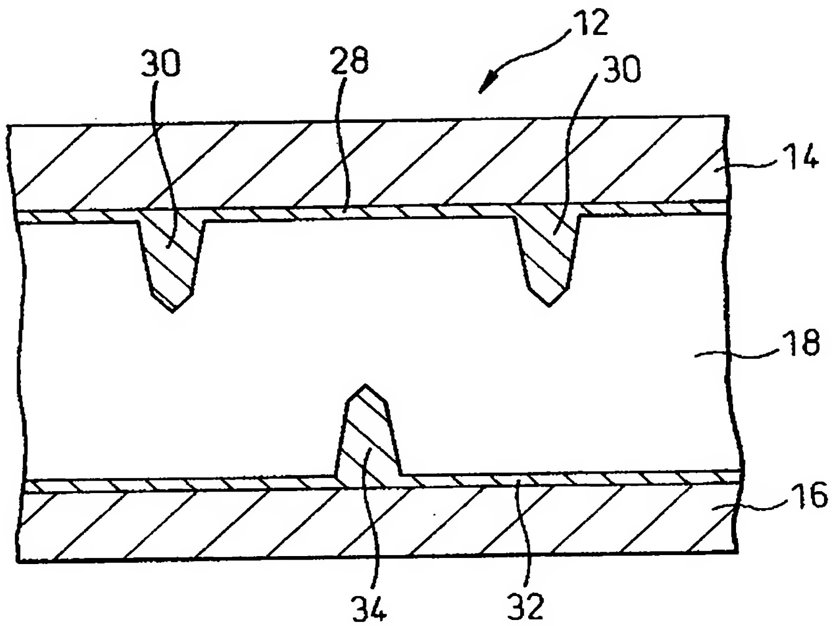
[Fig.30]

図 30



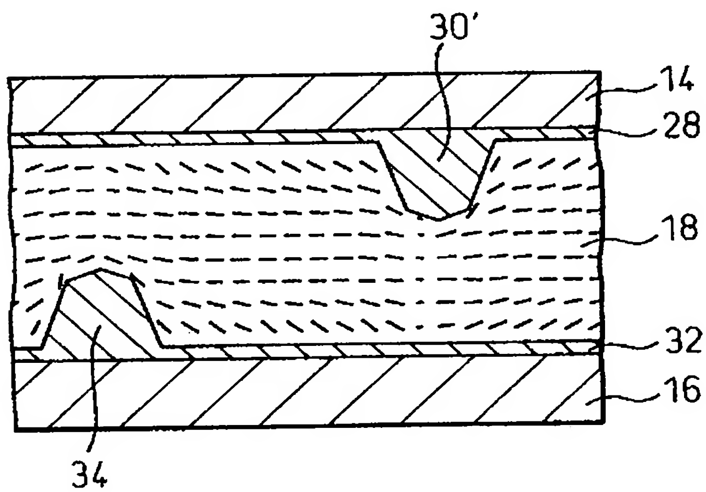
[Fig.31]

図 31



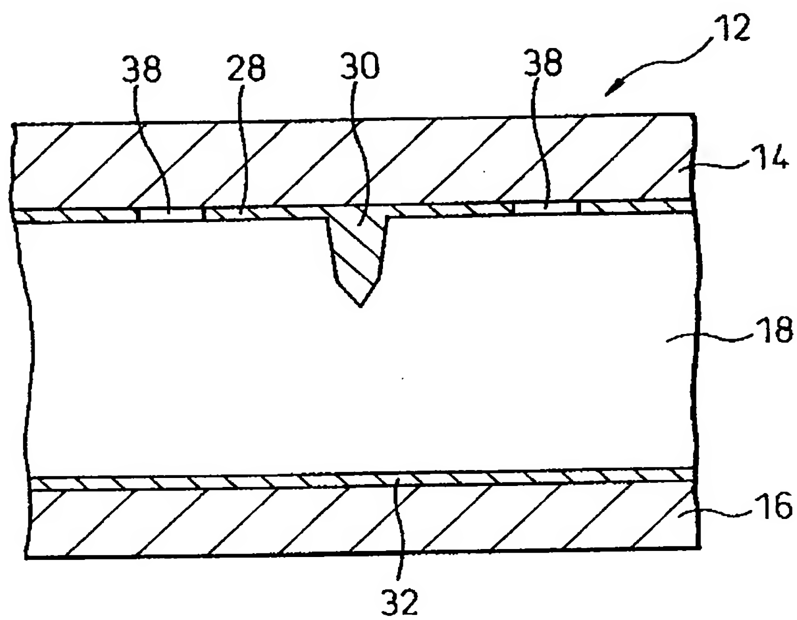
[Fig.32]

図 32



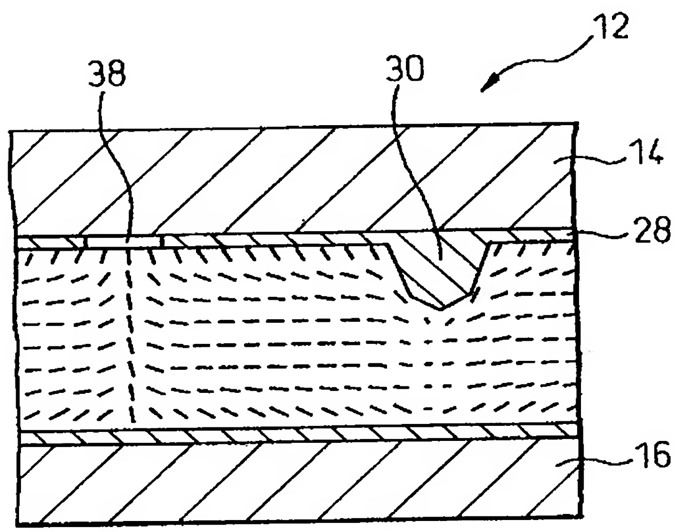
[Fig.33]

図 33



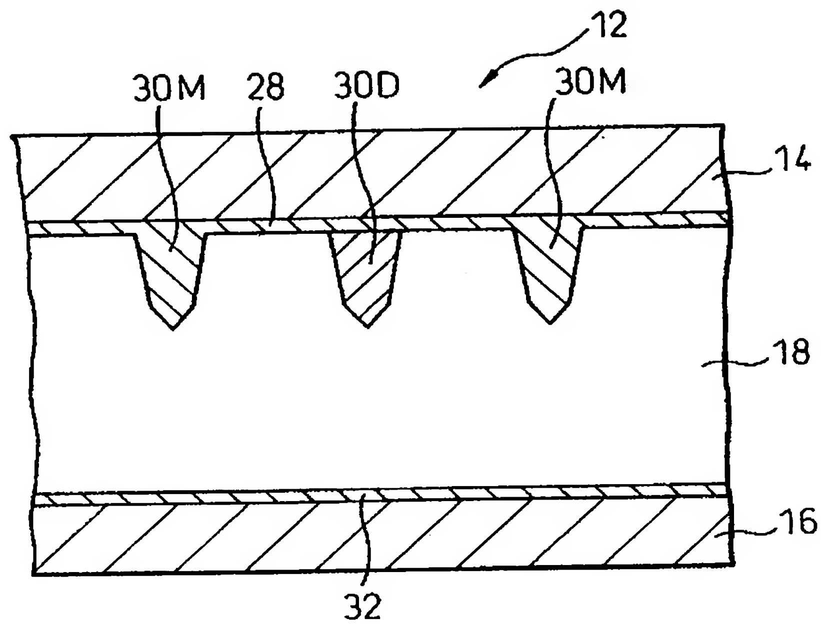
[Fig.34]

図 34



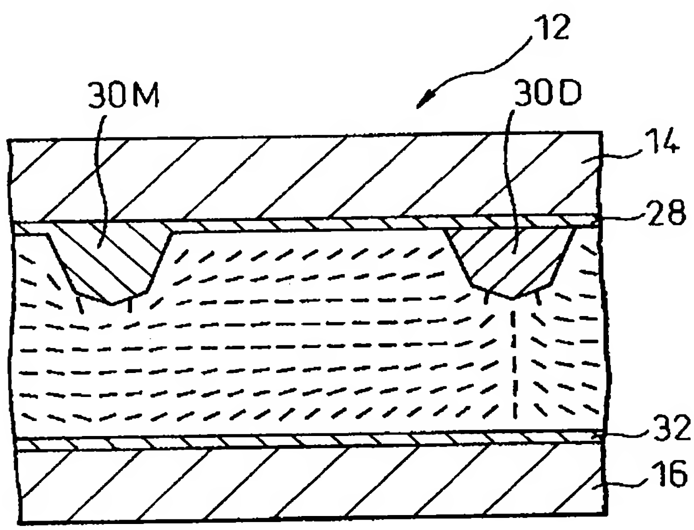
[Fig.35]

図 35



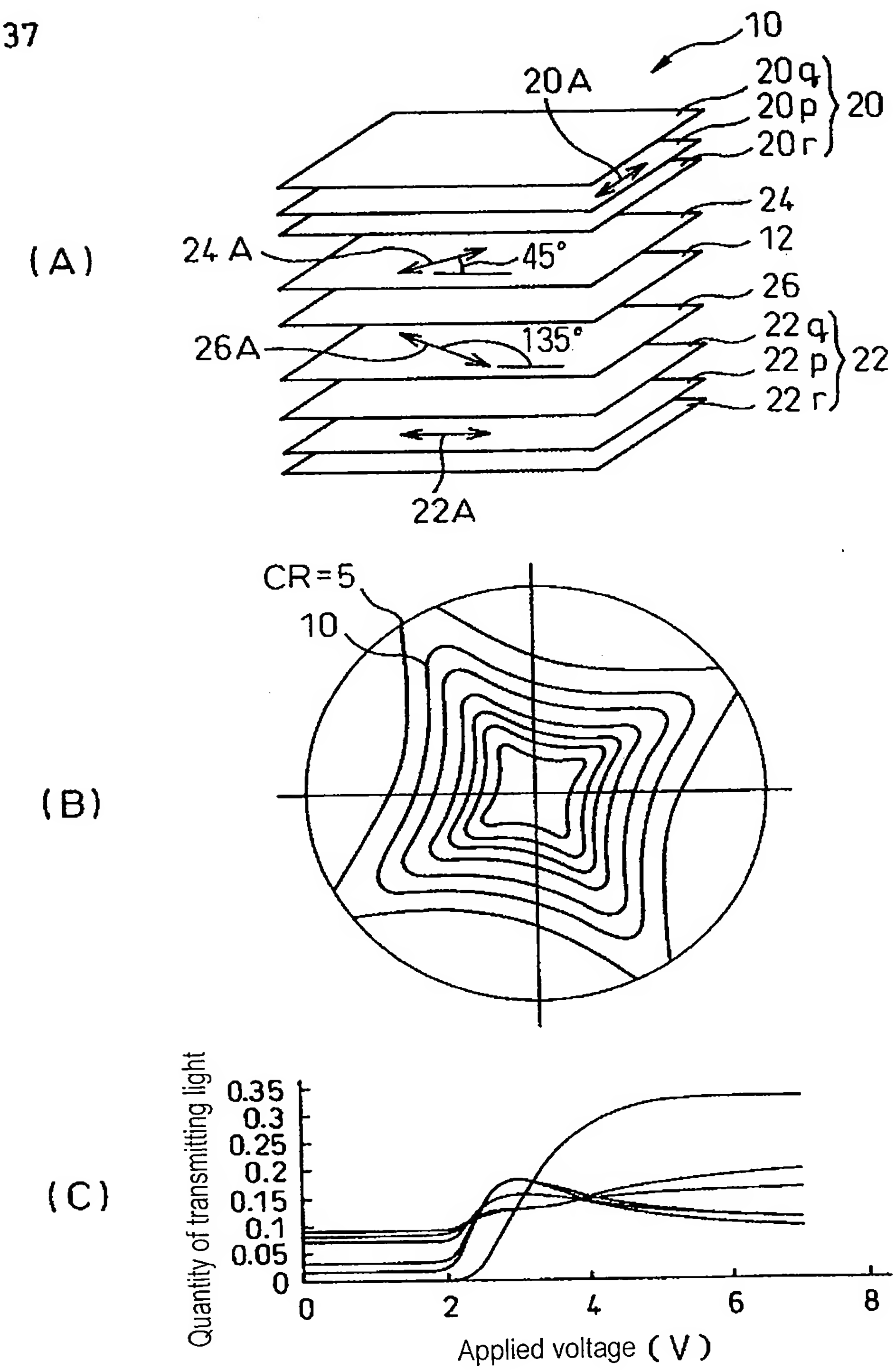
[Fig.36]

図 36



[Fig.37]

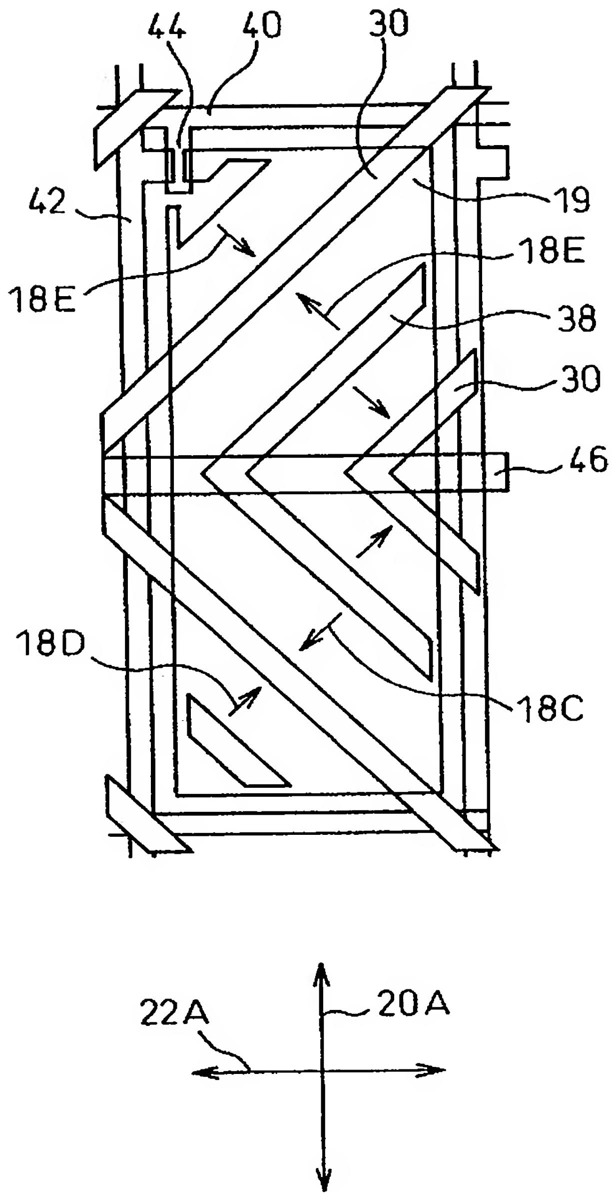
図 37



10
20A
20q
20p
20r
20
24
12
24 A
45°
26
26A
135°
22q
22p
22r
22
22A
(A)
CR=5
10
(B)
(C)
Quantity of transmitting light
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
2
4
6
8
Applied voltage (V)

[Fig.38]

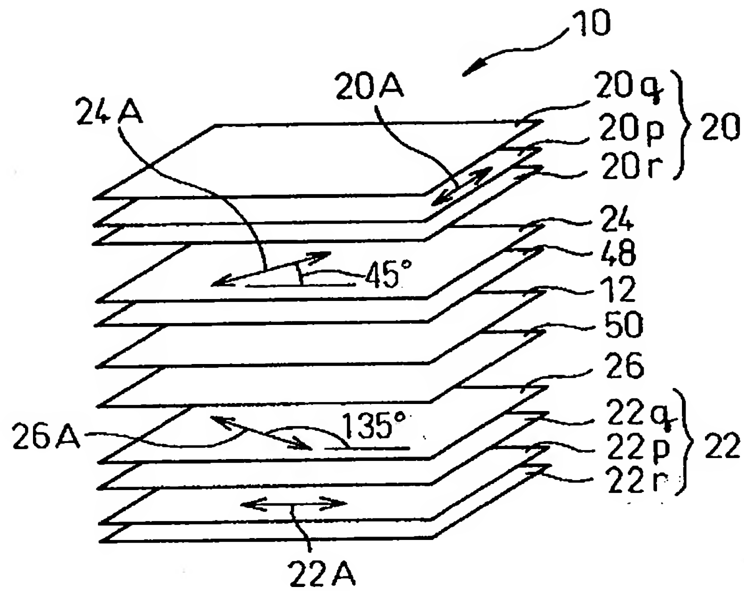
図38



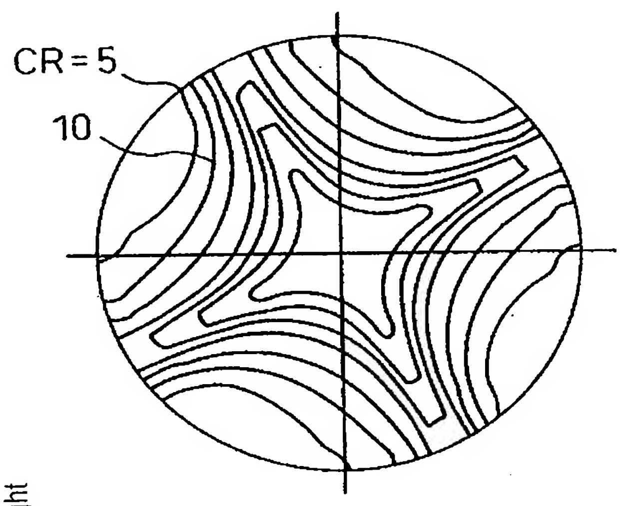
[Fig.39]

図 39

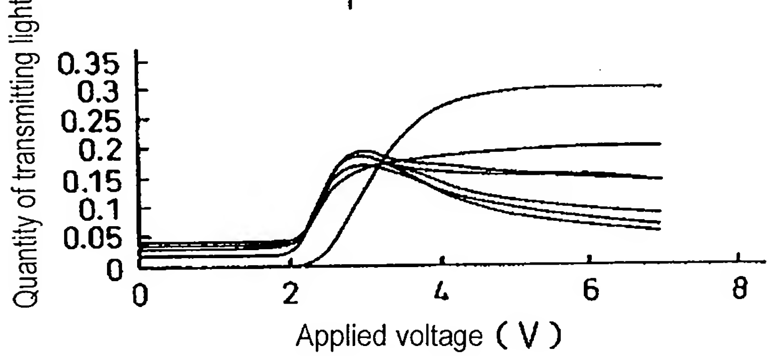
(A)



(B)



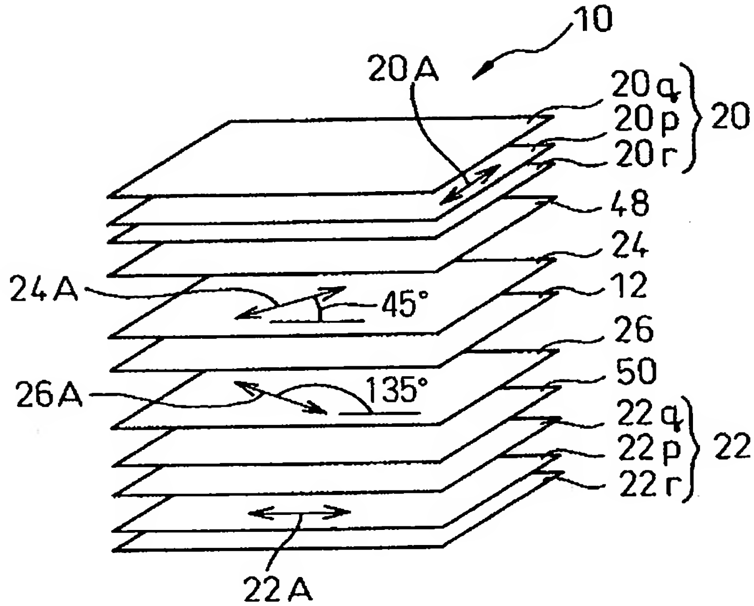
(C)



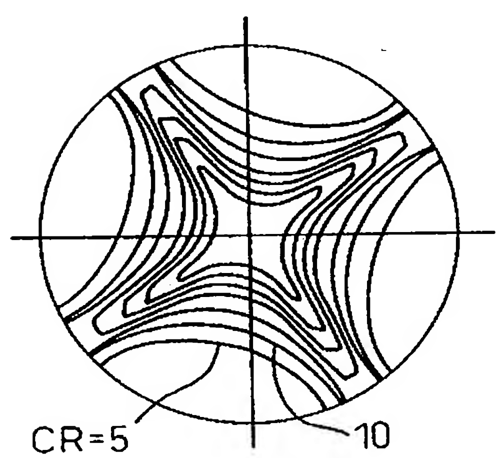
[Fig.40]

図 40

(A)

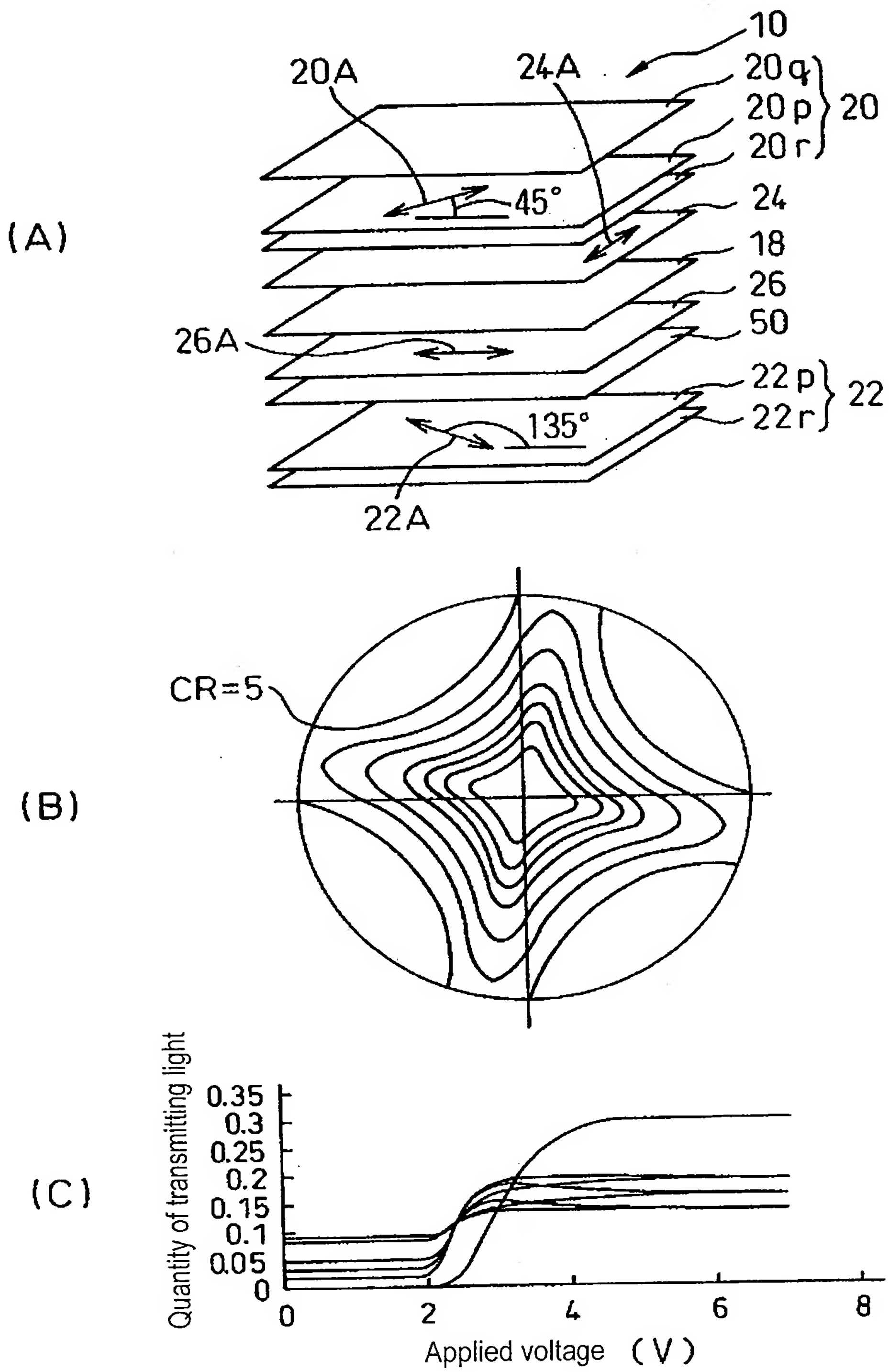

10
20A
20q
20p
20r
20
48
24
12
24A
45°
26
50
26A
135°
22q
22p
22r
22
22A

(B)


CR=5
10

[Fig.41]

図41


(A)
10
20A
24A
20q
20p
20r
20
24
18
26
50
45°
26A
22p
22r
22
135°
22A
(B)
CR=5
(C)
Quantity of transmitting light
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
2
4
6
8
Applied voltage (V)

[Fig.42]

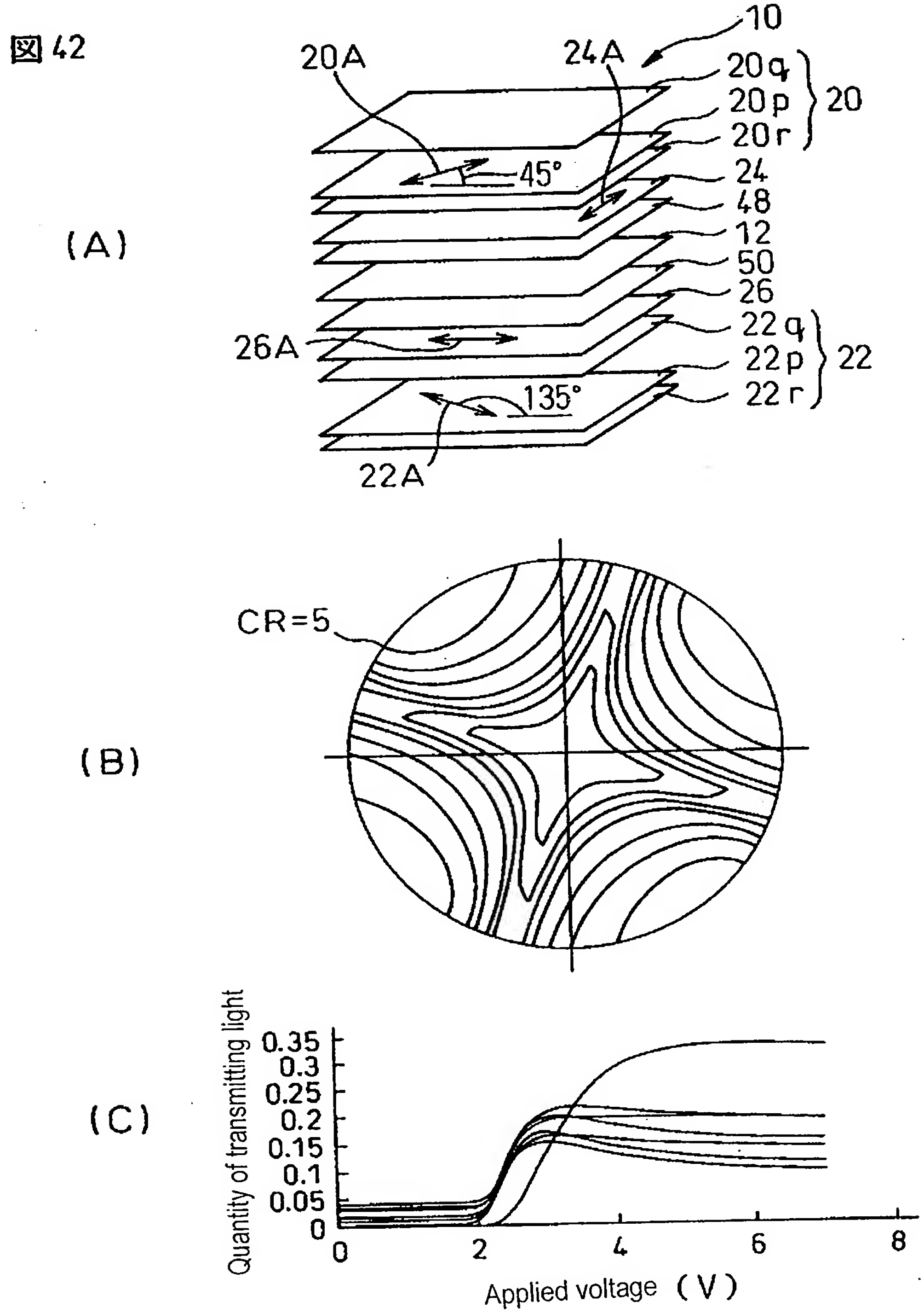
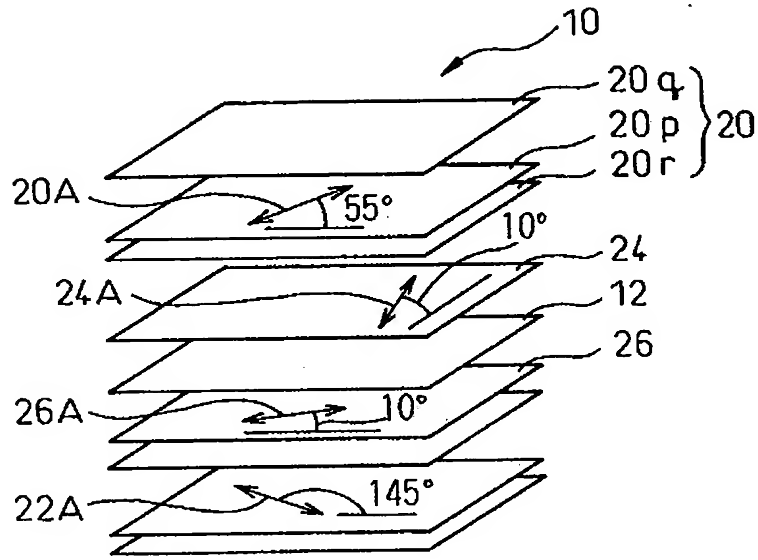


図 42
(A)
10
20A
24A
20q
20p
20
20r
45°
24
48
12
50
26
26A
22q
22p
22
22r
135°
22A
(B)
CR=5
(C)
Quantity of transmitting light
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
2
4
6
8
Applied voltage (V)

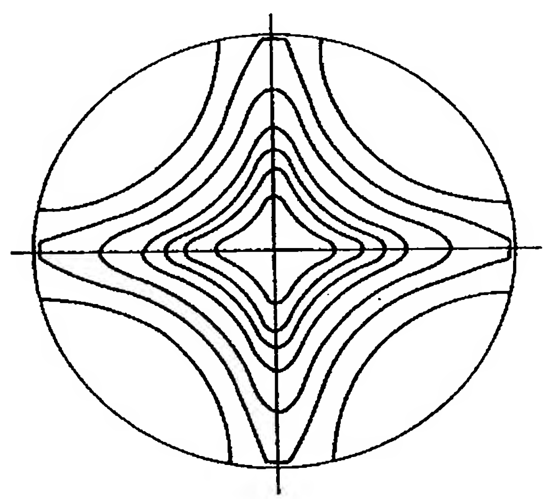
[Fig.43]

図 43

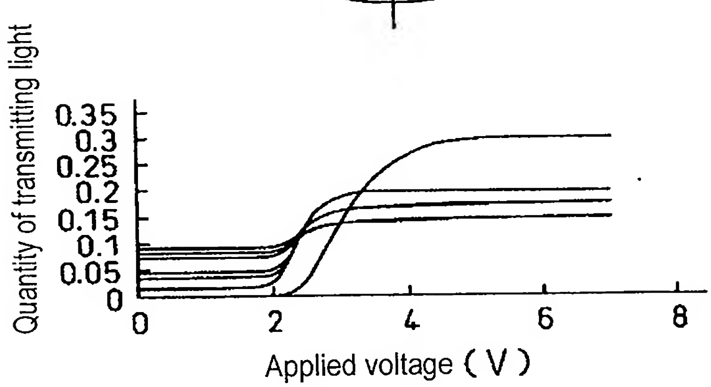
(A)



(B)



(C)



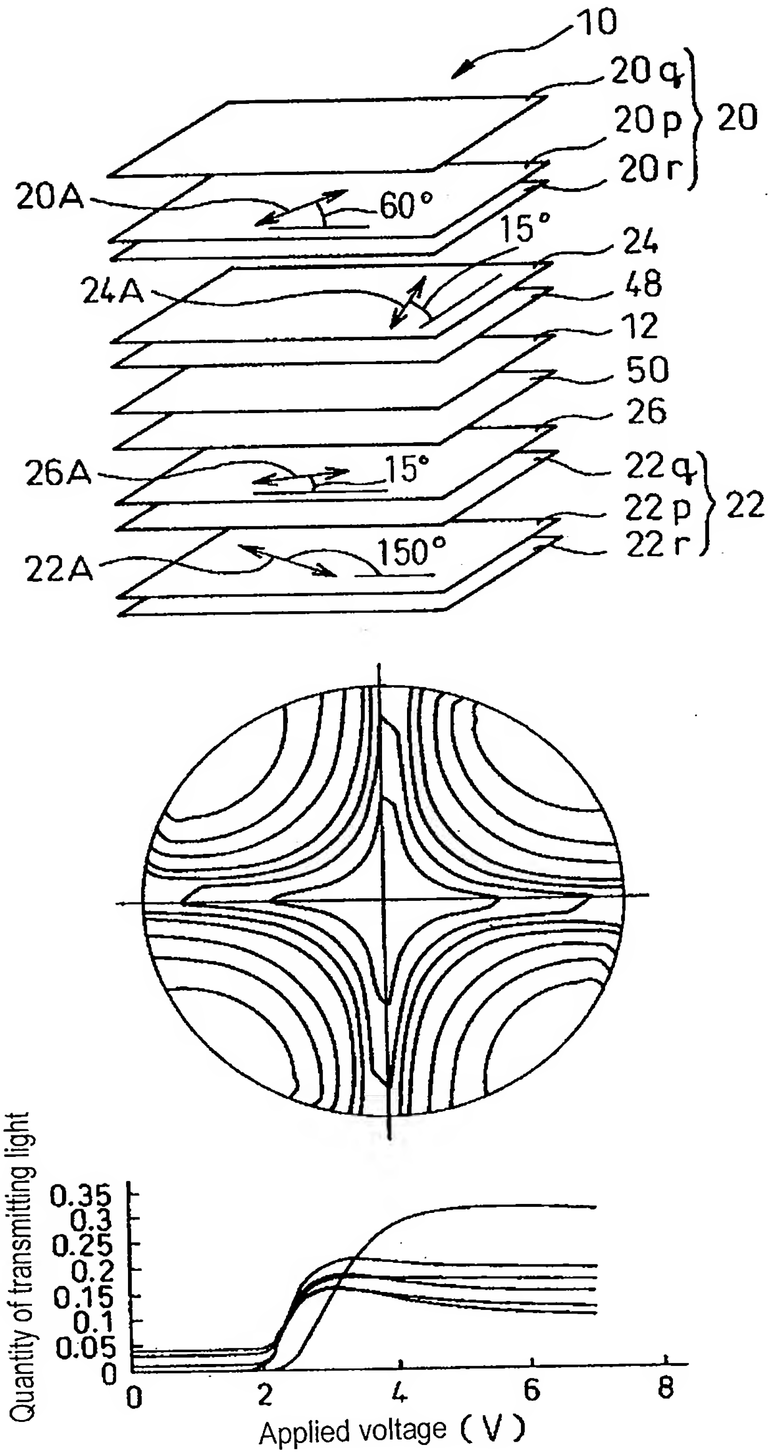
[Fig.44]

図 44

(A)

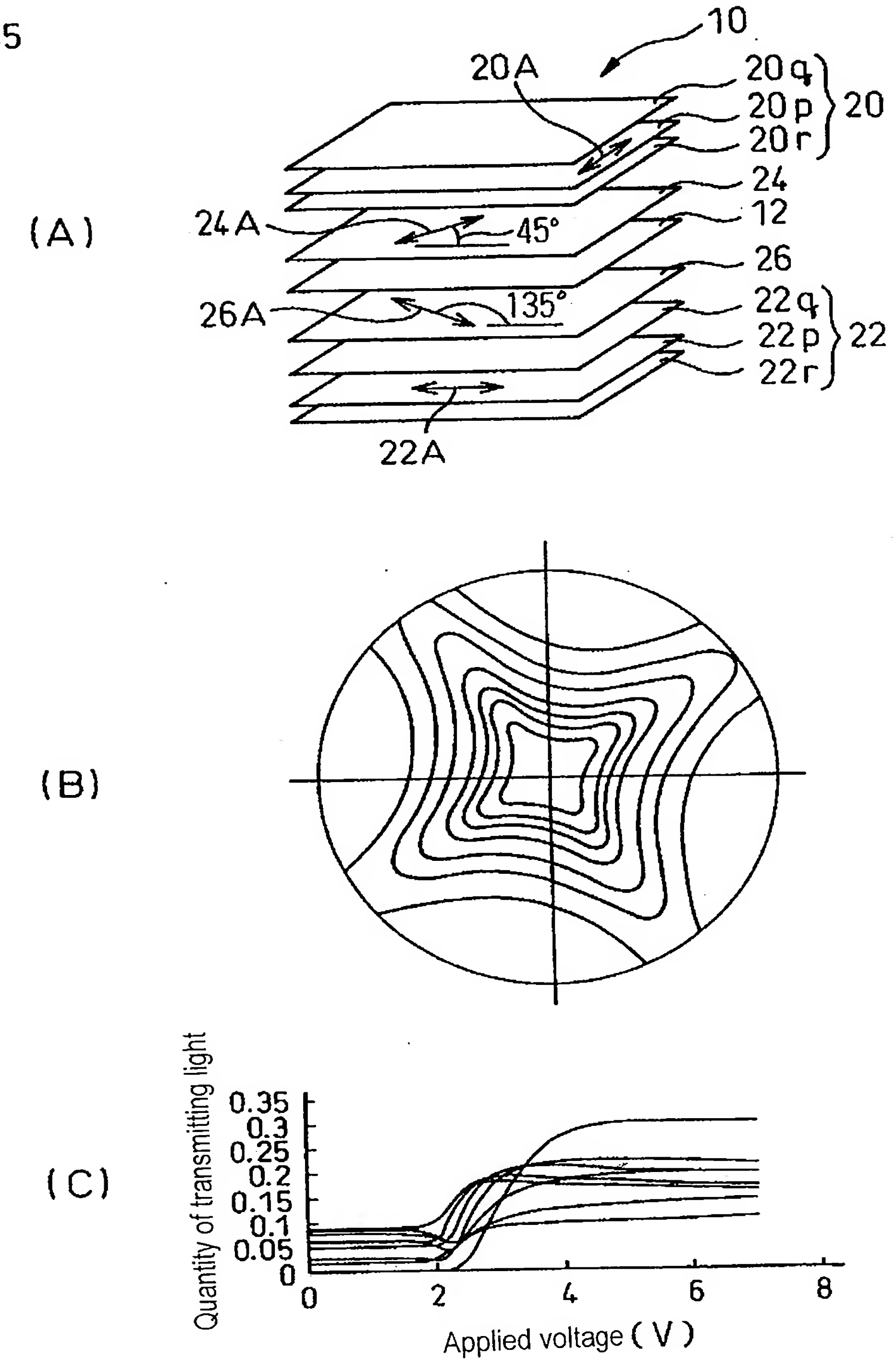
(B)

(C)



[Fig.45]

図 45


10
20A
20q
20p
20r
20
24
24A
45°
12
26
26A
135°
22q
22p
22r
22
22A
(A)
(B)
(C)
Quantity of transmitting light
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
2
4
6
8
Applied voltage (V)

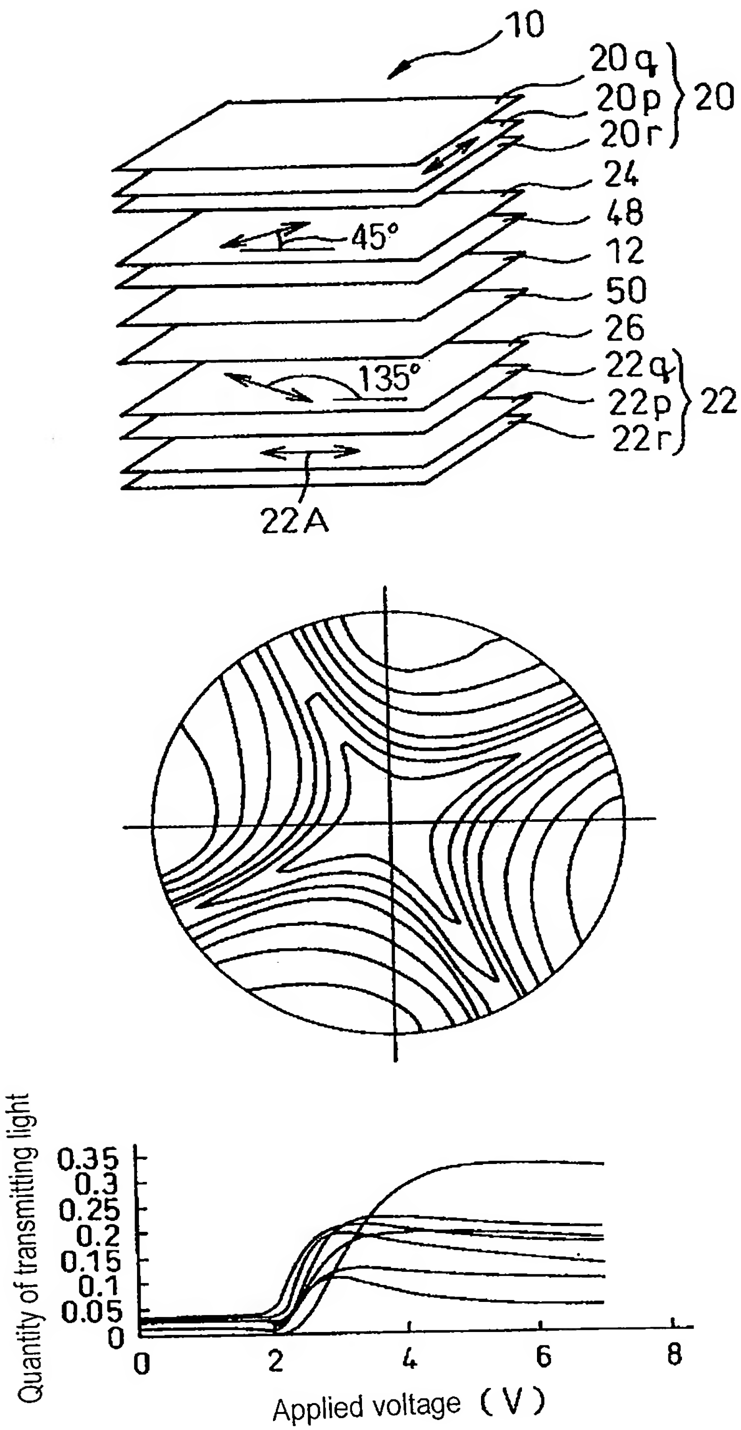
[Fig.46]

図 46

(A)

(B)

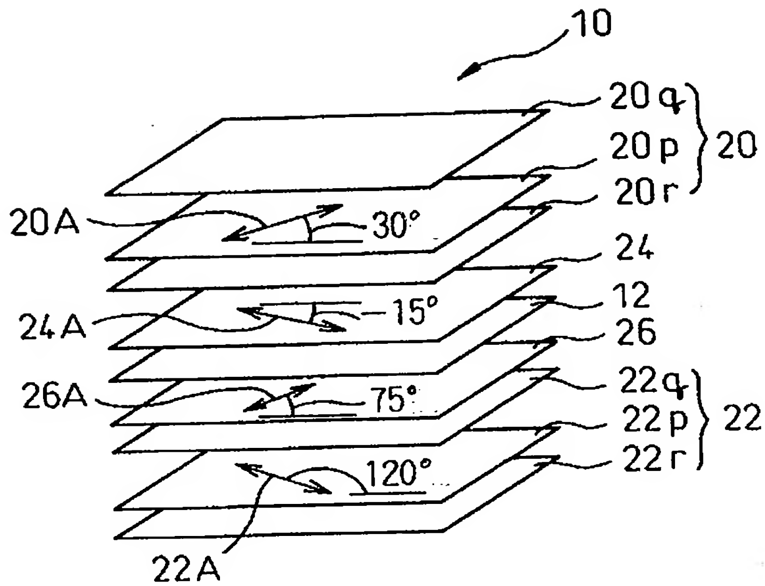
(C)



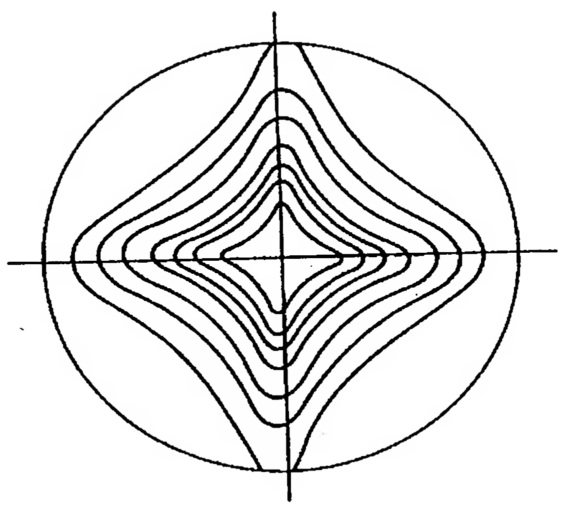
[Fig.47]

図47

(A)

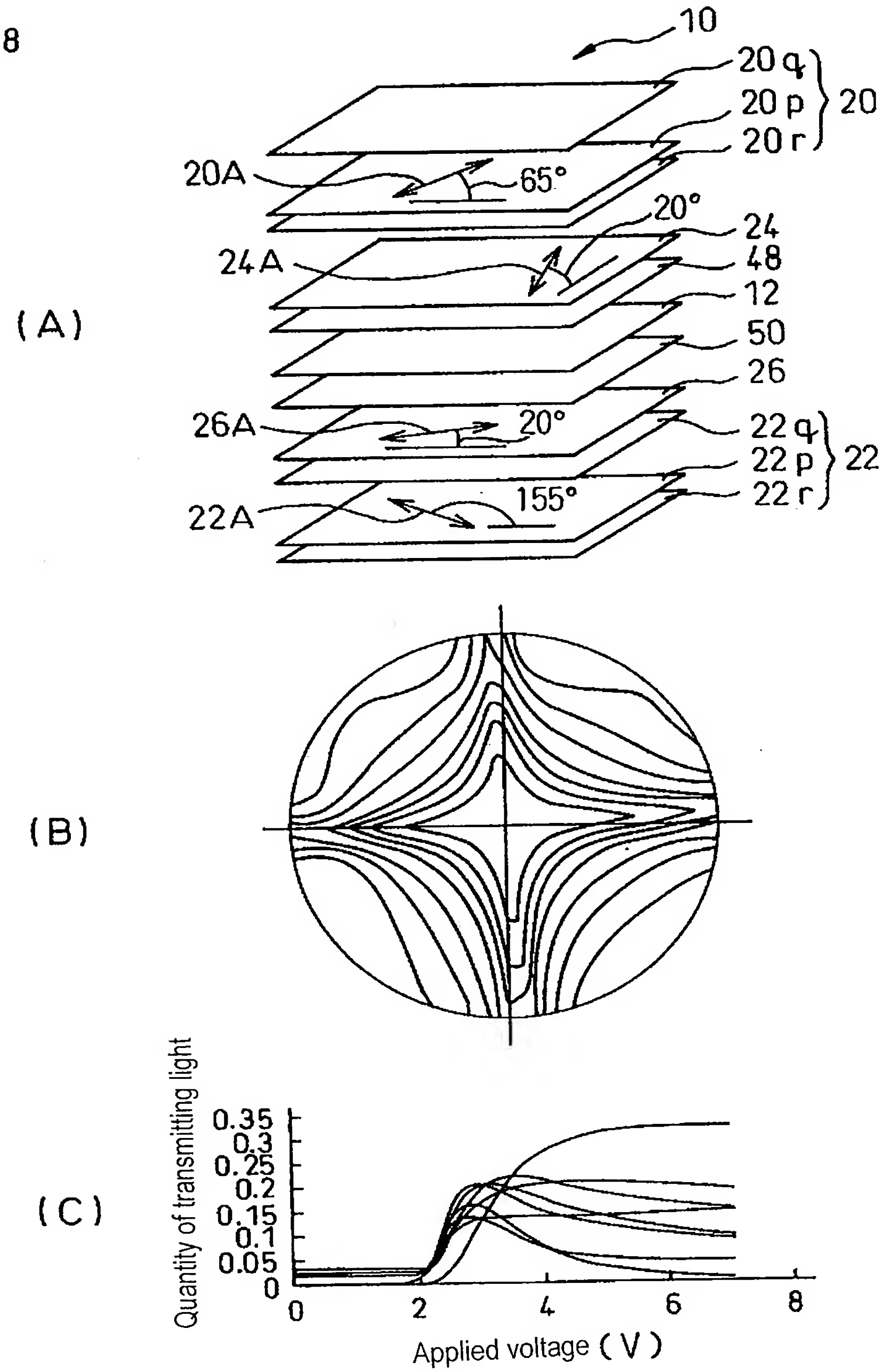

10
20q
20p
20r
20
20A
30°
24
12
24A
15°
26
26A
75°
22q
22p
22r
22
120°
22A

(B)



[Fig.48]

図 48


10
20q
20p
20r
20
20A
65°
20°
24
24A
48
12
50
26
26A
20°
22q
22p
22r
22
22A
155°
(A)
(B)
(C)
Quantity of transmitting light
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
2
4
6
8
Applied voltage (V)

[Fig.49]

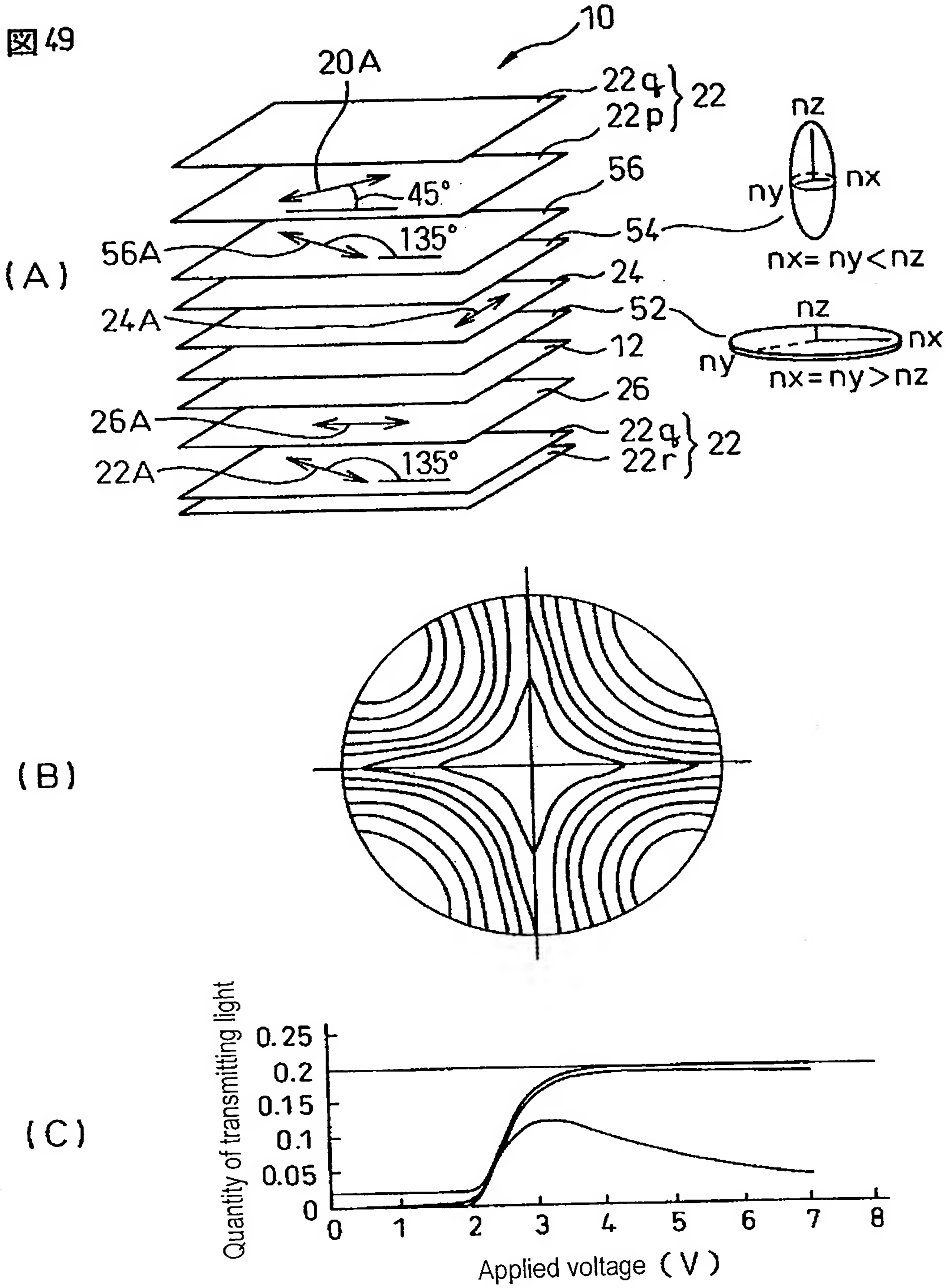


図49
10
20A
22q
22p
22
56
45°
135°
56A
54
nz
ny
nx
nx= ny<nz
(A)
24
24A
52
nz
nx
ny
nx=ny>nz
12
26
26A
22q
22r
22
22A
135°
(B)
(C)
Quantity of transmitting light
0.25
0.2
0.15
0.1
0.05
0
0
1
2
3
4
5
6
7
8
Applied voltage (V)

[Fig.50]

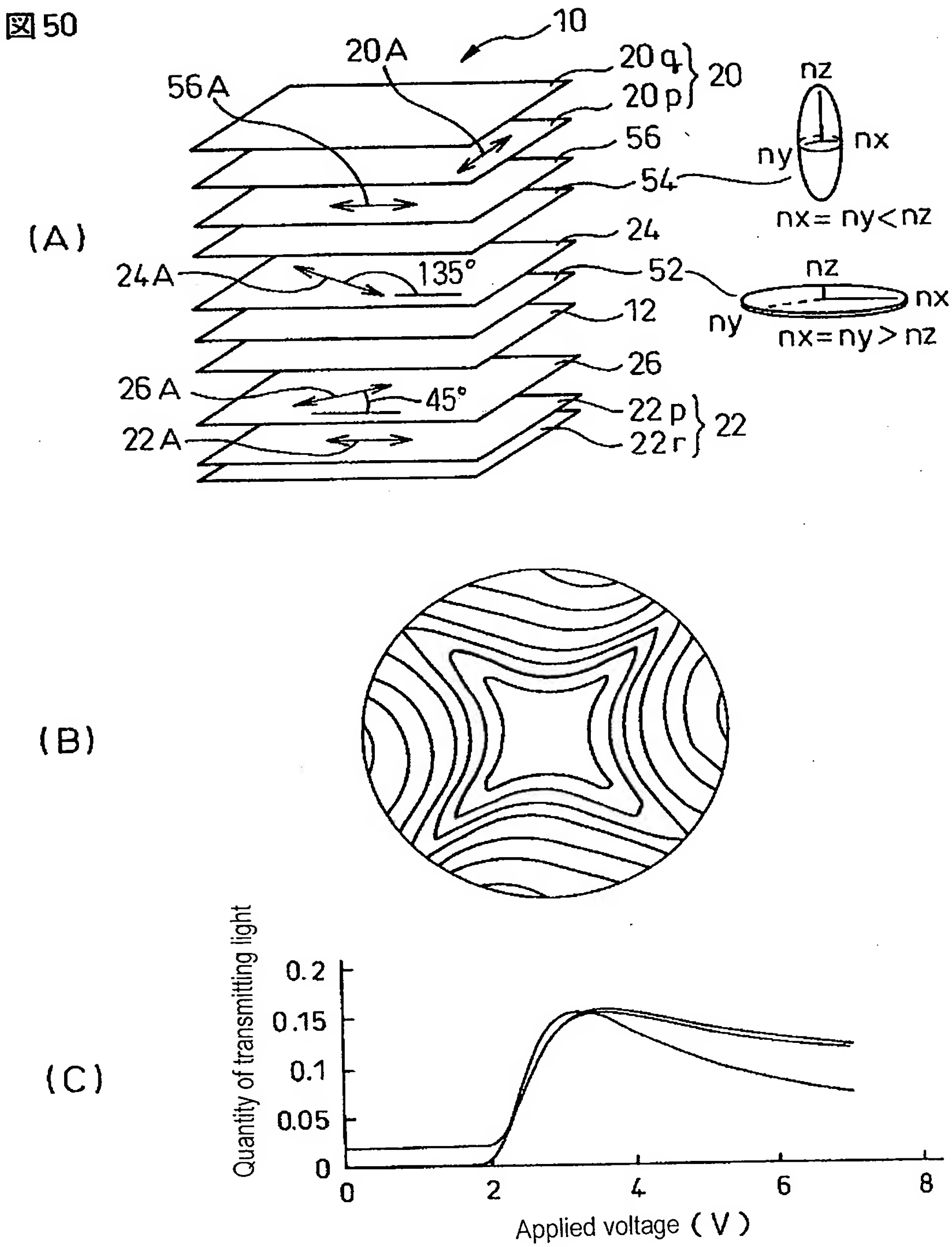


図50
10
20A
56A
20q
20p
20
56
54
24
52
12
26
22p
22r
22
24A
135°
26A
45°
22A
(A)
nz
nx
ny
nx= ny<nz
nz
nx
ny
nx=ny>nz
(B)
(C)
Quantity of transmitting light
0.2
0.15
0.1
0.05
0
0
2
4
6
8
Applied voltage (V)

[Fig.51]

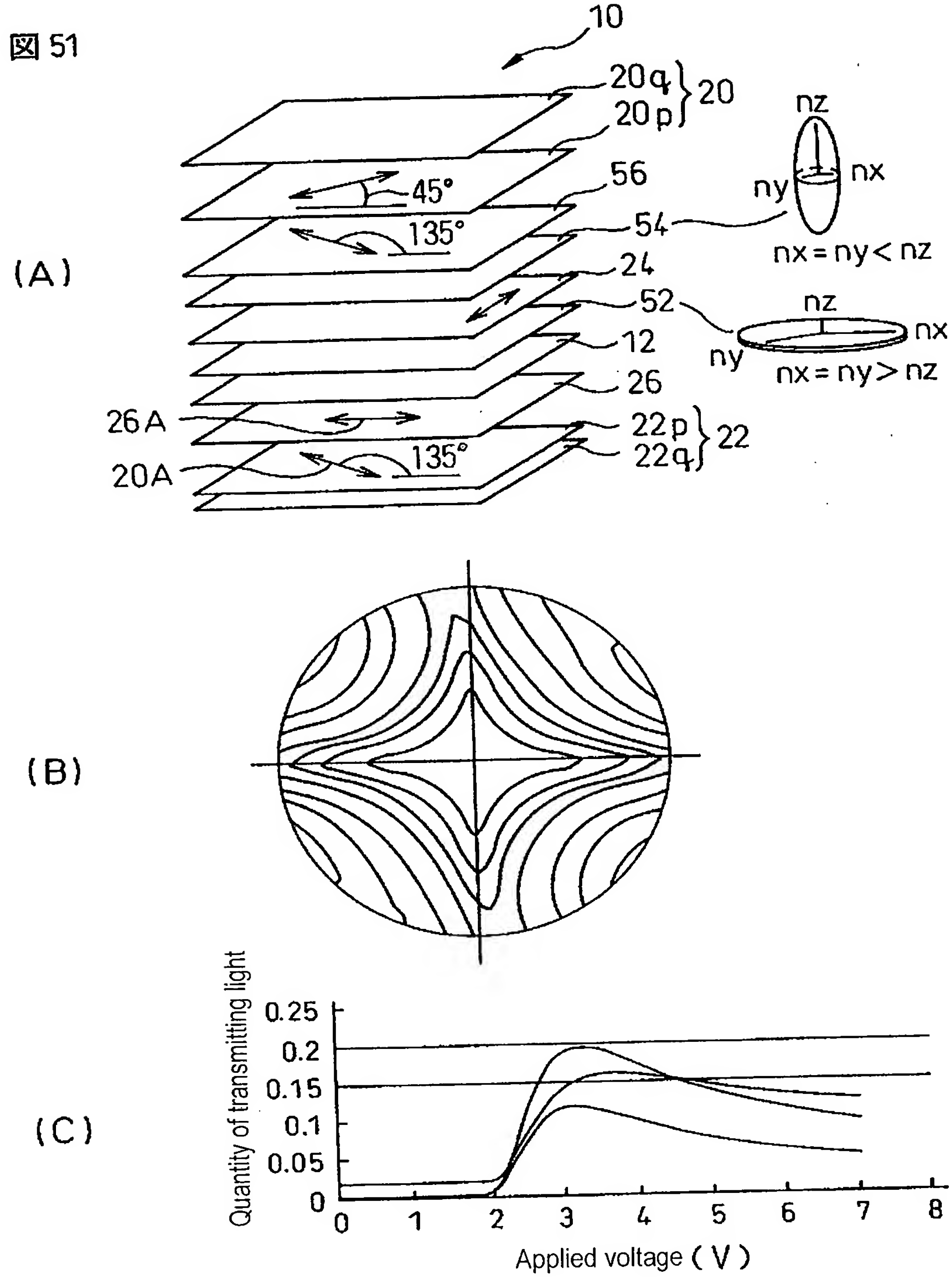


図 51
10
20q
20p
20
56
45°
135°
54
24
52
12
26
26A
22p
22q
22
20A
135°
nz
nx
ny
nx = ny < nz
nz
nx
ny
nx = ny > nz
(A)
(B)
(C)
Quantity of transmitting light
0.25
0.2
0.15
0.1
0.05
0
0
1
2
3
4
5
6
7
8
Applied voltage (V)

[Fig.52]

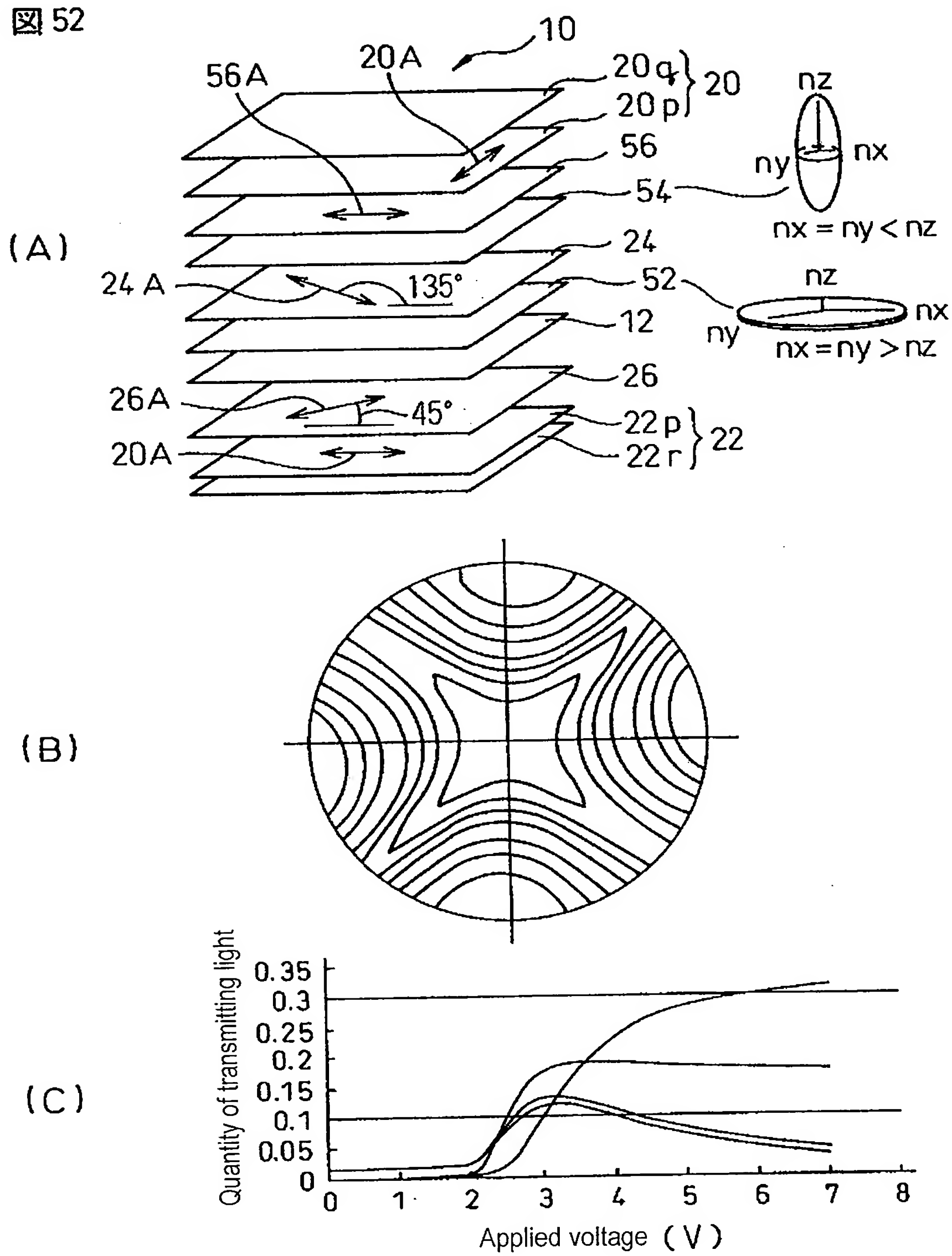
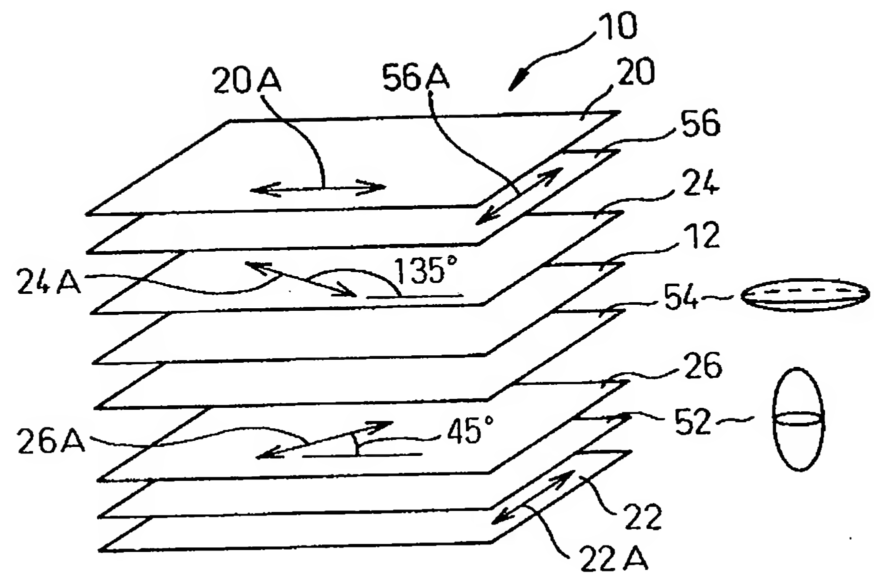


図52
10
20A
56A
20q
20p
20
56
54
24
52
12
26
22p
22r
22
24A
135°
26A
45°
20A
(A)
nz
nx
ny
nx = ny < nz
nz
nx
ny
nx = ny > nz
(B)
(C)
Quantity of transmitting light
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
1
2
3
4
5
6
7
8
Applied voltage (V)

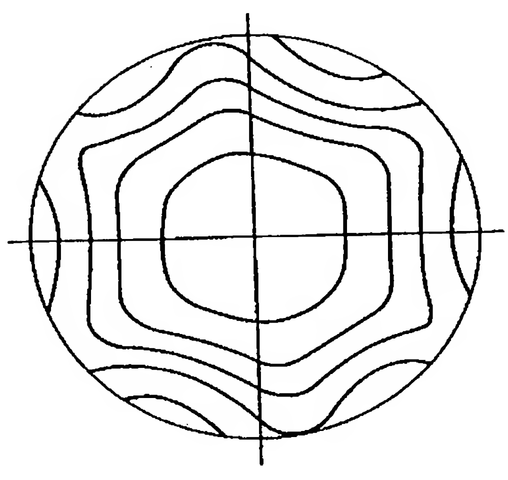
[Fig.53]

図 53

(A)

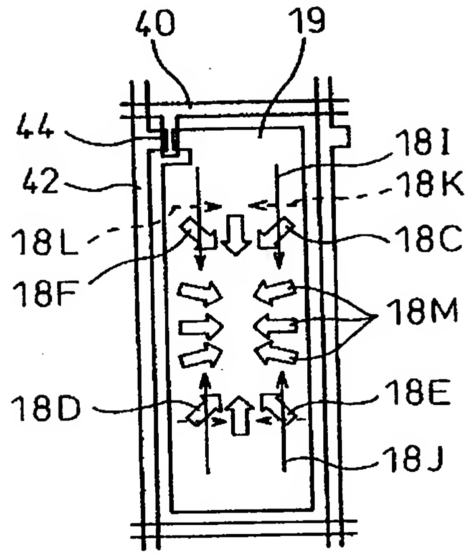


(B)



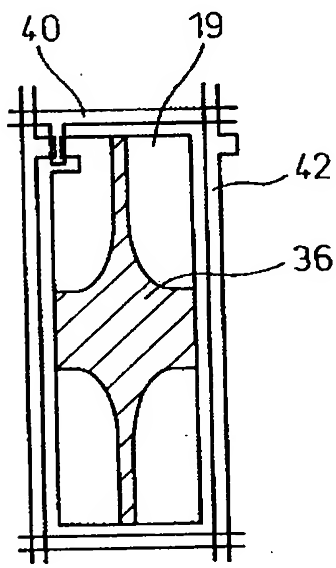
[Fig.54]

図 54



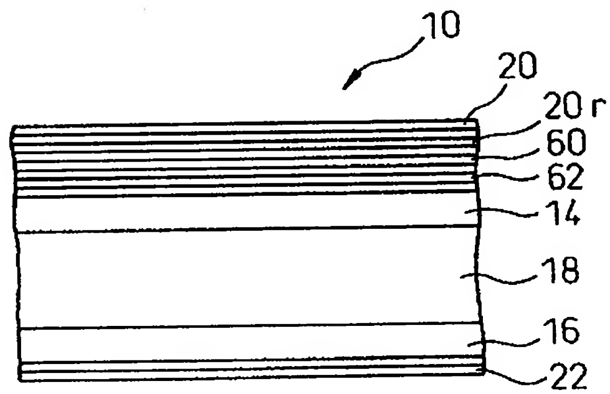
[Fig.55]

図 55



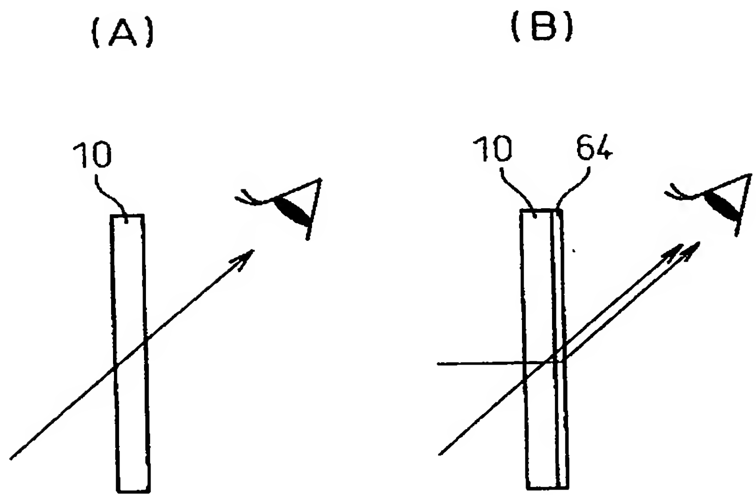
[Fig.56]

図56



[Fig.57]

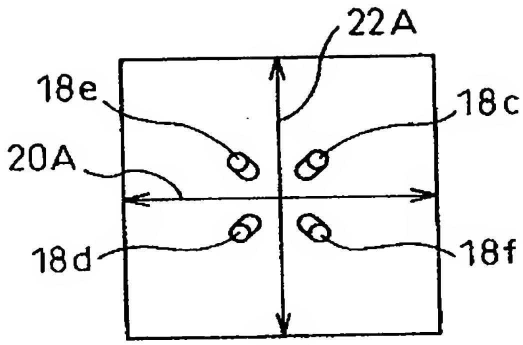
図57



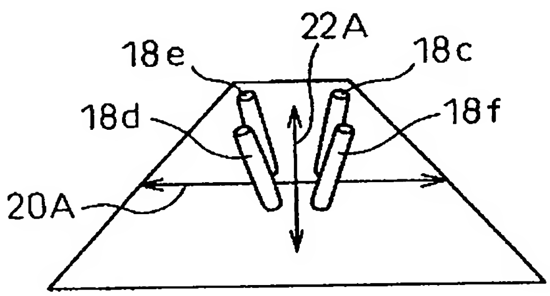
[Fig.58]

図 58

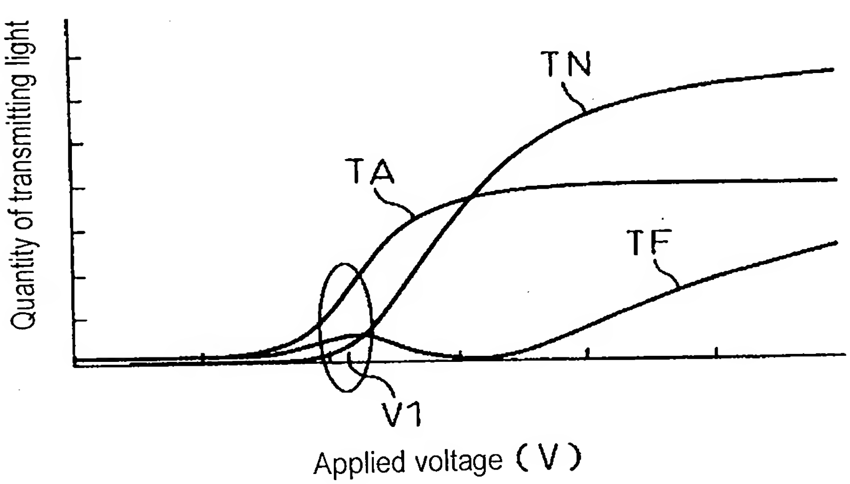
(A)



(B)

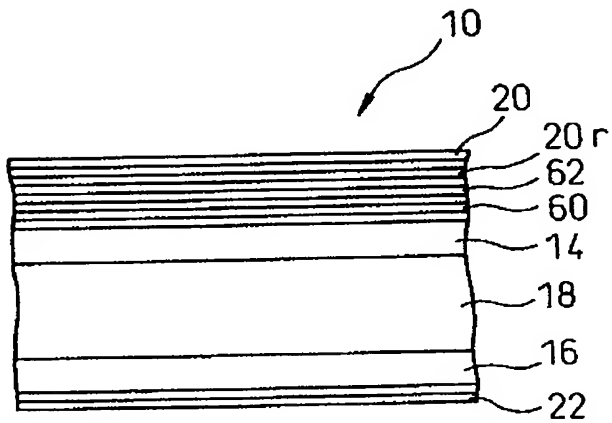


(C)



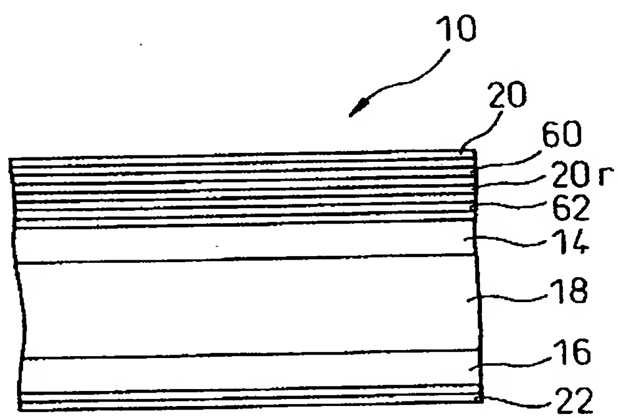
[Fig.59]

図59



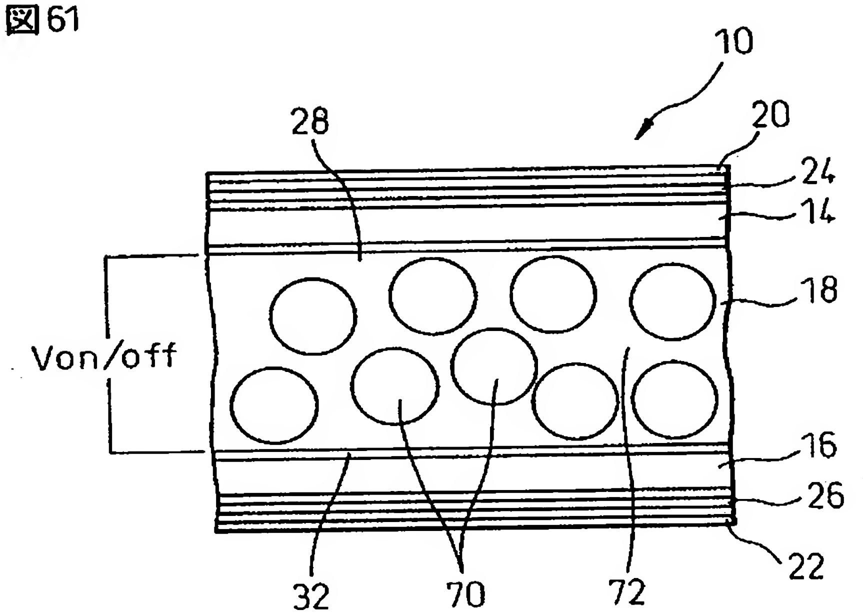
[Fig.60]

図60



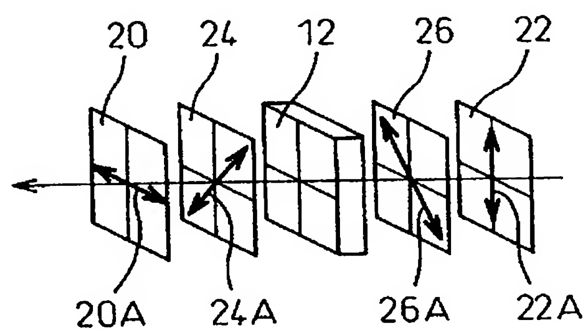
[Fig.61]

図61



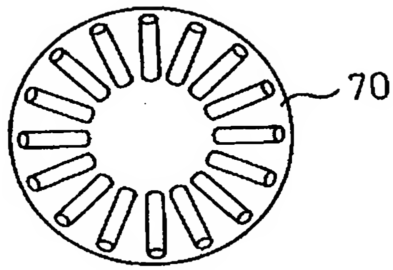
[Fig.62]

図 62



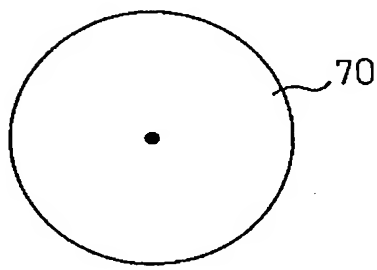
[Fig.63]

図 63



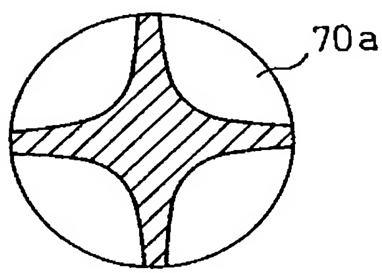
[Fig.64]

図 64



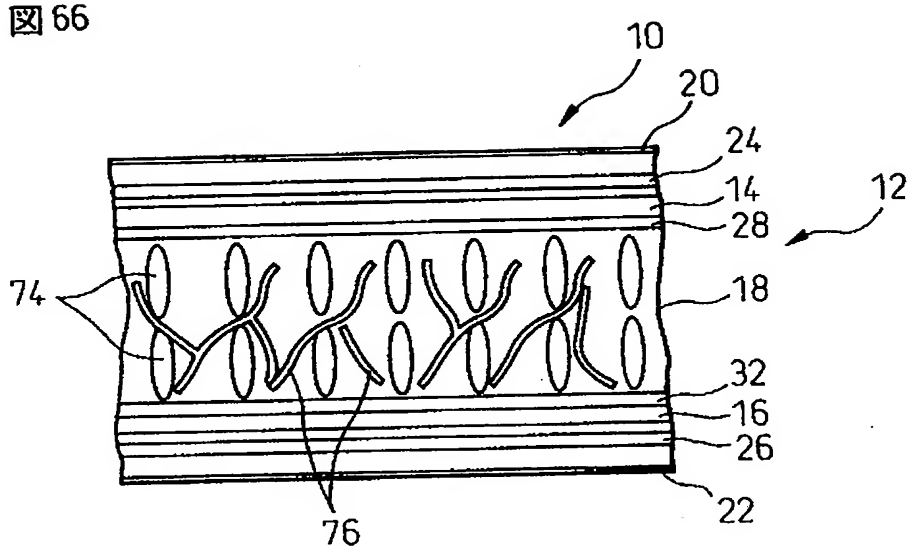
[Fig.65]

図 65



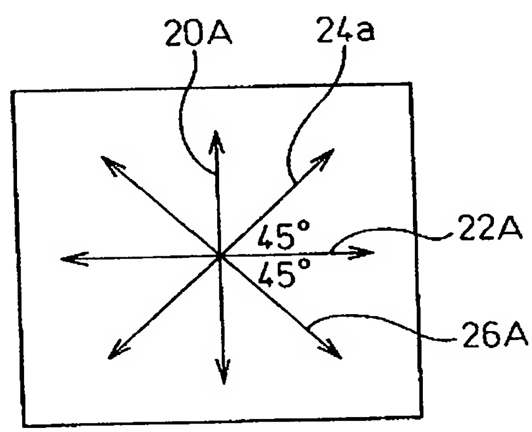
[Fig.66]

図 66



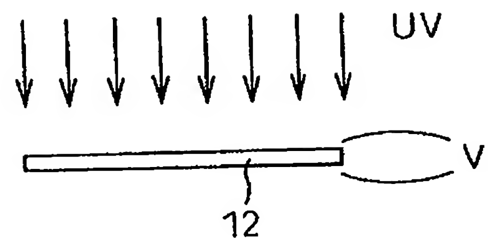
[Fig.67]

図 67



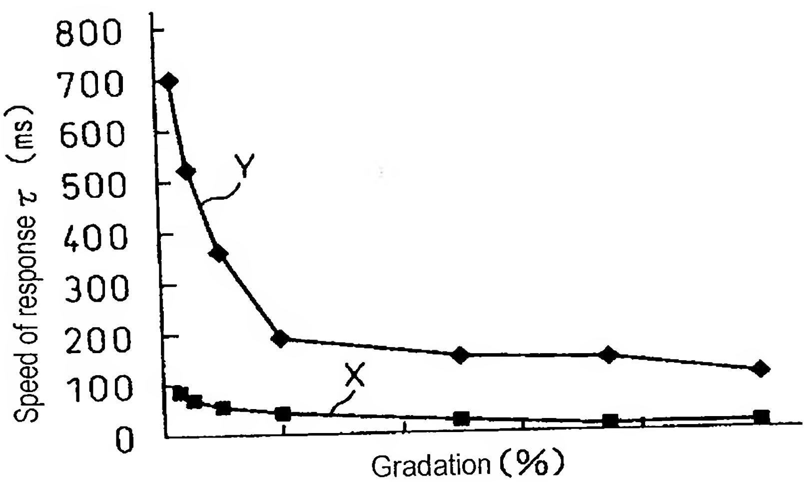
[Fig.68]

図68



[Fig.69]

図69



[Fig.70]

図70